EVALUATING COLUMBUS, GEORGIA, TREE CANOPY INTERACTIONS WITH AIR POLLUTANTS USING HIGH SPECTRAL IMAGERY AND PORTABLE PM SENSORS

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ABSTRACT

Trees provide environmental, economic, and social advantages in urban areas. Knowing the extent and location of tree canopy in a municipality is an important step in quantifying these benefits. Spatial and temporal tree canopy analysis was performed for the city of Columbus, Georgia, by categorizing the National Agriculture Imagery Program (NAIP) aerial imagery for 2005, 2010 and 2015 into tree versus non-tree land cover type using unsupervised classification procedures. Air pollution removal rates from the i-Tree program were applied to this evaluation providing an estimate of the city's tree air quality benefits. The city's canopy overall has remained steady at 52% of the 38,143 hectares that compose the municipality for the years 2005 (89% accuracy), 2010 (93% accuracy) and 2015 (93% accuracy). Percent tree canopy within the city's 53 census tracts ranged from 13 to 75%. Tree loss due to development in south central, north, and north-eastern areas was offset by forest regrowth, having been cleared prior to 2005. These trees remove 1,700 tonnes of five critical air pollutants (CO, NO_2, O_3, $PM_{2.5}$, PM_{10}, and SO_2) and sequester 256,000 tonnes of CO_2 annually, based on i-Tree's first-order valuations.

Since trees influence fine particulate matter ($PM_{2.5}$) and the health impacts of $PM_{2.5}$ are great, a second study was conducted to better understand how tree stand formation controls $PM_{2.5}$. Three portable, fine PM sensors (AirBeams) were used among three tree canopy configurations (dense tree buffer, n=5; small tree line, n=6; and U-shaped, n=4) to determine if stand design effects $PM_{2.5}$ concentrations in open areas near trees. AirBeams were evaluated and found to have reliability, ease of use, repeatability among units, and stability across the study period. Overall results between open and tree concentrations were not significantly different. Site by site observations indicated that dense tree buffers (3 of the 5 sites) trap $PM_{2.5}$ resulting in higher tree particulate concentrations in the buffer zone and small tree lines (5 sites) had no

effect on $PM_{2.5}$. U-shaped tree stands interactions are dependent on location of the open area within the tree stand in relation to notable PM sources. While wind direction played a role in particulates reaching sampling locations, proximity to and type of PM source had the largest impact on local $PM_{2.5}$ concentrations.

Urban canopy cover recommendations are made so cities can benefit from ecosystem services that trees provide, but simply adding trees does not mean these benefits are fully utilized. Tree type, tree design, and tree placement, i.e. in available space and proximity to pollution source, need to be considered. Utilizing high spectral imagery and low-cost, portable sensors can help cities determine the best tree placement and design to aide in air pollution reduction.

INDEX WORDS: tree canopy, high spectral resolution, particulate matter, AirBeam, unsupervised classification, aerial imagery, remote sensing

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ABBREVIATIONS

BAM – *b*-attenuation analyzer

EPA – Environmental Protection Agency

GIS – Geographic Informational Systems

GSD – Ground Sample Distance

NAIP – National Agricultural Imagery Program

PM – particulate matter

$PM_{2.5}$ – PM < 2.5 μm in diameter

PM_{10} – PM > 2.5 μm and < 10 μm in diameter

TEOM – Tapered Element Oscillating Microbalance analyzer

UFORE – Urban Forest Effects

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Dr. Samuel Abegaz Date

INTRODUCTION

Trees provide many benefits in urban areas, such as improving air quality, sequestering carbon dioxide (Nowak & Crane, 2002), filtering water (Booth, 2005), and decreasing urban heat islands (Bolund & Hunhammar, 1999). These environmental benefits also have health advantages, like improving senior longevity (Takano, Nakamura, & Watanabe, 2002), lowering the number of autism cases (Wu & Jackson, 2017), and lowering mortality with cleaner air (Tiwary, 2009). People value trees mostly for their shade, air quality improvements, and "calming effects" (Lohr, Pearson-Mims, Tarnai, & Dillman, 2004). The economic gains to a city can include everything from lower crime rates (Kuo & Sullivan, 2001) to increased housing prices that generate property tax revenues (Anderson & Cordell, 1988; Donovan & Butry, 2010).

Researchers have taken different approaches to understanding the values of trees. Top-down approaches involve quantifying trees regionally by classifying high spectral imagery into landcover classes including tree canopy cover (Nowak, 2012). Canopy is defined as the area of land covered by tree leaves, trunks, and branches as seen from an aerial perspective (Northern Research Station, 2017). Once canopy is analyzed, models can be applied to the findings to estimate tree benefits (McPherson & Simpson, 2002; Nowak & Crane, 2000). Conversely, field studies aimed at quantifying tree benefits in a locale are preferred, especially when few field studies exist to support models that apply air quality values to trees (Pataki et al., 2011; Setälä, Viippola, Rantalainen, Pennanen, & Yli-Pelkonen, 2013).

While all ecosystem services and economic attributes provided by trees are important, this research focuses on the removal of air pollutants by trees. The first investigation looks at the value of applying broad level air quality assessment to cities using high spectral canopy analysis and air pollutant removal rates, obtained from the i-Tree Tool (www.i-Tree.org), for Columbus,

Georgia, a municipality in western Georgia, USA. The air pollutant removal rates using the i-Tree Tool are based on first-order approximations, with environmental and meteorological data from one location often accounting for several counties in a region. As such, local research should assist in determining services and possible disservices of tree placement or removal practices (Nowak & Greenfield, 2008; Nowak et al., 2014). While other limitations exist in using the i-Tree model, fine particulate matter ($PM_{2.5}$) is the one pollutant that poses additional specific limitations. The i-Tree model's $PM_{2.5}$ uses a positive removal rate in counties with low wind and a negative removal rate (meaning increase in $PM_{2.5}$) in counties with high wind and low rain (Hirabayashi, 2014). Trees are a temporary resting location for $PM_{2.5}$, and local weather conditions, especially wind and precipitation, can resuspend particles into the air or bring to the ground (Nowak et al., 2014). As a result, it was determined that the second part of this research would focus on tree and fine particulate matter interactions by tree buffer arrangement, as this interaction is more complex than other air pollutants removed from the air column by trees.

Particulate matter (PM) is among the six criteria air pollutants regulated by the Environmental Protection Agency (EPA) under the National Ambient Air Quality Standards (NAAQS) as part of the Clean Air Act (Girard, 2014). $PM_{2.5}$ causes major health related issues when inhaled (Hemon & Fechner, 2014), and has been linked to over 100,000 deaths annually in the United States (Fann et al., 2012).

Study Goals and Scope

As the city of Columbus was the first city in the state to become Tree City USA certified (and has remained so for 39 years; GFC, 2012), maintaining a working knowledge of the tree canopy and its services (or disservices) in the community is vital. The goal of this research is to pair spatial and temporal analysis of canopy with air quality monitoring to quantify tree benefits

and aide in future tree planning for the city of Columbus. The final product will contain: a thematic tree canopy map and percentage breakdown of tree canopy by census tract for 2005, 2010 and 2015; tree canopy change over the ten-year period; a first-order estimation of Columbus air quality benefits; and the results of a field study examining tree effects on local $PM_{2.5}$ levels within tree canopy stands and adjacent open areas.

CHAPTER 1 – SPATIAL AND TEMPORAL CANOPY COVER ANALYSIS

1.1 Introduction

Municipalities for decades have focused on vegetative planning to improve water filtration, reduce air pollutants, support economic growth, and abate climate change (Howard, 1965; Miller, 1988; Platt, Rowntree, & Muick, 1994; Young, 2010; Escobedo, Kroeger, & Wagner, 2011; Roy, Byrne, & Pickering, 2012). Urban planning often incorporates these ecosystem services into local urban design with vegetation in mind, but determining what to account for, whether air pollution abatement, social improvements, or economic values take priority, is complex (Thomas & Geller, 2013). Knowing the amount and location of tree canopy in an urban environment is a mandatory first step as municipalities plan for future development.

The term canopy, for the purposes of this research, means the area of land covered by tree leaves, trunks, and branches as seen from an aerial perspective (Northern Research Station, 2017). US cities and counties produce Urban Tree Canopy (UTC) assessments using high spectral aerial or satellite imagery to classify land cover thereby ascertaining tree canopy amount and distribution. The USDA Forest Service's Northern Research Station and the University of Vermont's Spatial Analysis Laboratory created procedures and have assisted cities in developing UTC assessments to help with urban tree planning (Northern Research Station, 2017). Municipalities use similar procedures by classifying high spectral imagery to assess tree canopy spatially and temporarily in order to enhance "green" planning. As an example, Atlanta, Georgia, completed a UTC assessment using satellite imagery (2-foot pan-sharpened, 4-band data) through the Georgia Tech Center for Geographic Information Systems in 2014. That assessment determined the city had 47.9 percent canopy cover in 2008 (Giarrusso & Smith, 2014).

Land cover classification using high spectral imagery is a top-down approach to determine tree canopy versus the bottom-up approach used when surveying individual trees in an area. Each approach has its advantages and disadvantages, with the top-down approach being the best approach for assessing amount and location of trees in larger areas the size of municipalities (Nowak, 2012). The use of imagery to assess different land cover types is based on the idea that dissimilar objects, like water, vegetation, and roads, have unique spectral signatures because they reflect and absorb wavelengths of electromagnetic radiation (EM) differently (Kachhwaha, 1983; Keranen & Kolvoord, 2014). For example, water absorbs red and near-infrared wavelengths (0.76–0.90 μm), while vegetation reflects these wavelengths (0.63–0.90 μm). This difference allows the two land types to be distinguished using multispectral imagery and image analysis programs, like ESRI ArcGIS (Fox, 2015). Multispectral imagery is composed of three to seven bands of pixels with values 0 to 255, lower values are darker and higher values are lighter. Each band represents either visible or infrared wavelength ranges, i.e. for Landsat images band 1 is visible blue (0.45 to 0.52 μm), band 2 is visible green (0.52 to 0.60 μm), band 3 is visible red (0.63 to 0.69 μm), band 4 is near infrared (0.76 to 0.90 μm), band 5 is short-wave infrared 1 (1.55 to 1.75 μm), band 6 is thermal infrared (10.4 to 12.5 μm), and band 7 is short-wave infrared 2 (2.08 to 2.35 μm). These bands are combined and analyzed based on known spectral signatures of objects to classify an area of concern (Keranen & Kolvoord, 2014; Fox, 2015).

Once a municipality's tree canopy is known, ecosystem services (i.e. air quality, water filtration, and reduction of urban heat) can be estimated using tree models, like i-Tree Tools (online tools and software developed by US Forest Service, Davey Tree Expert Company, National Arbor Day Foundation, Society of Municipal Arborists, International Society of

Arboriculture, and Casey Trees) and ArcGIS based CITYGreen (software developed by American Forests with rates based on Urban Forest Effects (UFORE) methods, an earlier version of i-Tree). These models estimate UTC effects on air pollutant removal and carbon dioxide sequestration and storage. These removal rates were established through modeling the combination of tree canopy across the United States, leaf area index values, pollution removal rates by trees given local pollutant concentrations, and pollutant deposition rates based on local meteorological data. For i-Tree, the monetary value of these ecosystem services was applied based on health incidences and associated costs that would be avoided with pollutant removal (Nowak, Hirabayashi, Bodine, & Greenfield, 2014). The UFORE model took a similar approach, but used fewer cities and applied monetary values based on prevented health and tourism loss (Nowak & Crane, 2000).

The i-Tree Tool are a good starting point for tree planning and quantifying associated benefits of city trees. The i-Tree Tool incorporates data from across the United States and assesses removal rates for five of the six criteria air pollutants (carbon monoxide - CO, nitrogen dioxide - NO_2, ozone O_3, particulate matter – broken into $PM_{2.5}$ and PM_{10}, and sulfur dioxide - SO_2). The model also applies sequestration and storage rates for carbon dioxide (CO_2). Empirical studies quantifying tree impacts on air quality are limited (Pataki et al., 2011), and models projecting tree reductions of air pollutants range from 0.13 percent for $PM_{2.5}$ removal in urban settings to 0.51 percent for ozone removal in rural settings (Nowak et al., 2014). Other research has quantified the ability of trees to reduce air pollutants, but the focus is on only one or two criteria air pollutants (reviewed in Nowak et al., 2014). The air pollutant removal rates using the i-Tree Tool are based on first-order approximations, with environmental and meteorological data from one location often accounting for several counties in a region. One

Italian study found good agreement when i-Tree ozone removal rates were compared to local level field measurements (Morani et al., 2014).

The Natural Resources Spatial Analysis Laboratory conducted a Georgia Land Use Trends analysis including tree cover for the state of Georgia. Landsat satellite data (30 m x 30 m resolution) was used to create GIS databases for the state with an overall accuracy of 85 percent for years 1974, 1985, 1991, 1998, 2001, 2005, and 2008 (Kramer, 2016). The study found an eight percent tree canopy loss in Muscogee County between 1991 and 2005 (GFC, 2012). The city of Columbus (consolidated with Muscogee County, Georgia) did not have a recent assessment of tree canopy nor a high resolution assessment needed for city wide tree planning.

Maintaining a working knowledge of the Columbus city tree canopy and its services (or disservices) in the community is important given the potential environmental implications. This research seeks to fill the knowledge gap regarding the city's tree canopy through spatial and temporal analysis of its UTC. The goal of this study is to assess the city of Columbus tree canopy and estimate its associated air quality benefits. The knowledge gained will aide in providing sound recommendations to the city on advantageous locations for future tree planting and removal and will enhance planning and policies concerning development with vegetation in mind.

Disparity in tree canopy can be found in a look at the spectral imagery of Columbus, Georgia. It is visibly apparent that a greater, healthier canopy exists in the northern portion of the area. The National Agriculture Imagery Program (NAIP) imagery is a rich green color above highway 80 (denoted in red in Figure 1). Conversely, tree canopy is scarce in the downtown industrial area (the portion of the city that appears greyish-white in the mid-west portion of the image). This contrast in percent canopy is consistent with the American Forests

recommendations for ideally 15 percent canopy in downtown and industrial and 50 percent canopy in suburban residential areas (American Forests, 2002). When disparity in canopy exists across the city, the environmental benefits of the urban trees are also unequal city-wide. Tree benefits are applied at a small scale given the spread of atmospheric conditions and sources of air pollutants in urban settings (Nowak & Greenfield, 2008; Tyrväinen, Pauleit, Seeland, & de Vries, 2005).

This research intends to answer the following question: will aerial imagery analysis, quantifying tree canopy spatially and temporally, highlight large tree canopy and air quality benefit disparities over time across the city of Columbus? It is hypothesized that a disparity will exist between tree canopy within the study domain, with northern areas of the municipality having the most canopy and downtown having least canopy, resulting in disproportionate air quality benefits across the city. Additionally it is hypothesized that the tree canopy will decrease over the time period examined.

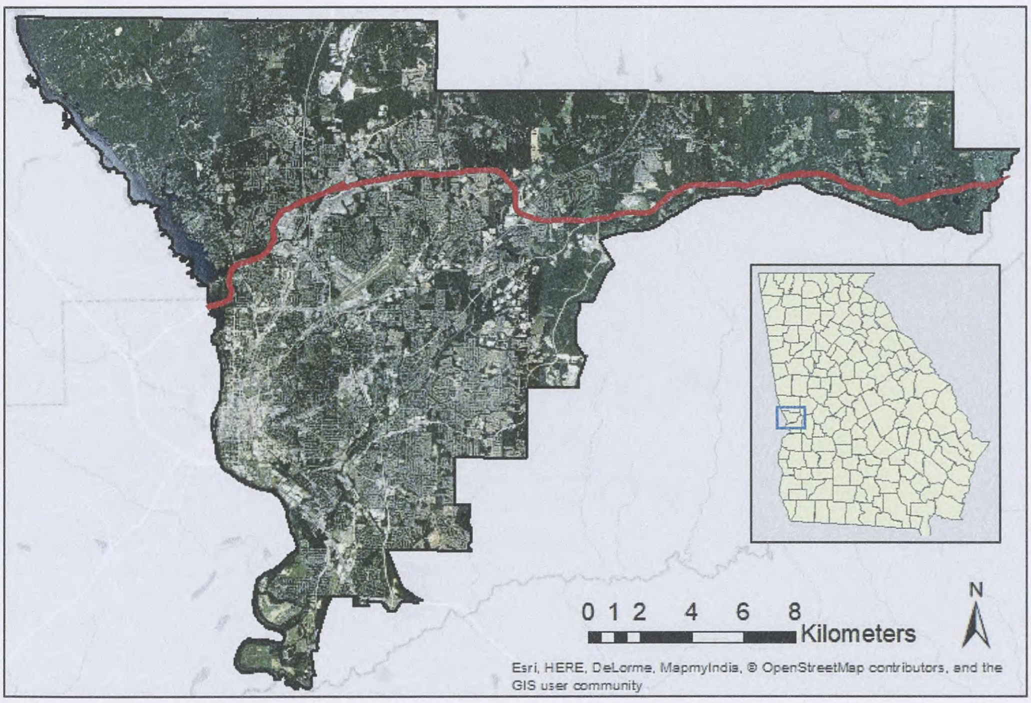


Figure 1. City of Columbus service region (excluding Fort Benning) 2015 1-meter, 4-band NAIP natural color image with inset map showing location of Columbus, Georiga.

1.2 Methods

1.2.1 Study Area – Columbus is located along the western border of Georgia, USA (Figure 1 inset, 32° 29' 32" N, 84° 56' 25" W). The city and county (Muscogee) governments are consolidated, therefore, the area of the city is the County land area of 56,045 ha (138,490 acres). Part of the Fort Benning Army base is located in southeastern Muscogee County. Excluding this portion of the County (17,902 ha), the city of Columbus has a land area of 38,143 ha (94,253 acres). The landscape to the north-northeast is dominated with agriculture and pine forest found throughout the southeastern United States, while the south-southwestern landscape is urban. Columbus is the second most populous municipality in Georgia with population of 189,885 in 2010 (U.S. Census Bureau, 2010).

1.2.2 High-Resolution Imagery - The 2010 and 2015 tree canopy were analyzed using the 1-meter ground sample distance (GSD) spatial resolution, 4-band National Agricultural Imagery Program (NAIP; 1m x 1m spatial resolution) imagery of Muscogee County. The 2005 tree canopy was analyzed using 2-meter GSD spatial resolution, 3-band NAIP imagery, as this is what was available. NAIP produces digital orthoimages roughly biannually (Georgia imagery exists for years 2001-2002, 2005-2007, 2009-2010, 2013, 2015, and 2017; USDA, 2017) by aerially photographing agricultural regions during the growing season, usually between July and September. The 1-meter GSD spatial resolution, available for free through the USDA program, offers the best resolution publicly available for Columbus in recurrent years, and it is, therefore, the best available imagery of the city accessible to city planners and other researchers for future tree canopy analysis. The 2005 NAIP imagery was obtained through the Columbus City Planning Department in compressed county mosaic format (Figure 2A). The 2010 city NAIP imagery was obtained from the U.S. Department of Agriculture Farm Service Agency, Aerial

Photography Field Office in Digital Ortho Quarter Quad (DOQQ) tiles format containing 25 separate DOQQ files (Figure 2B). The 2015 NAIP imagery was available online to download via the Aerial Photography Field Office in compressed county mosaic format (Figure 1). All three were projected in the UTM coordinate system, North American Datum of 1983.

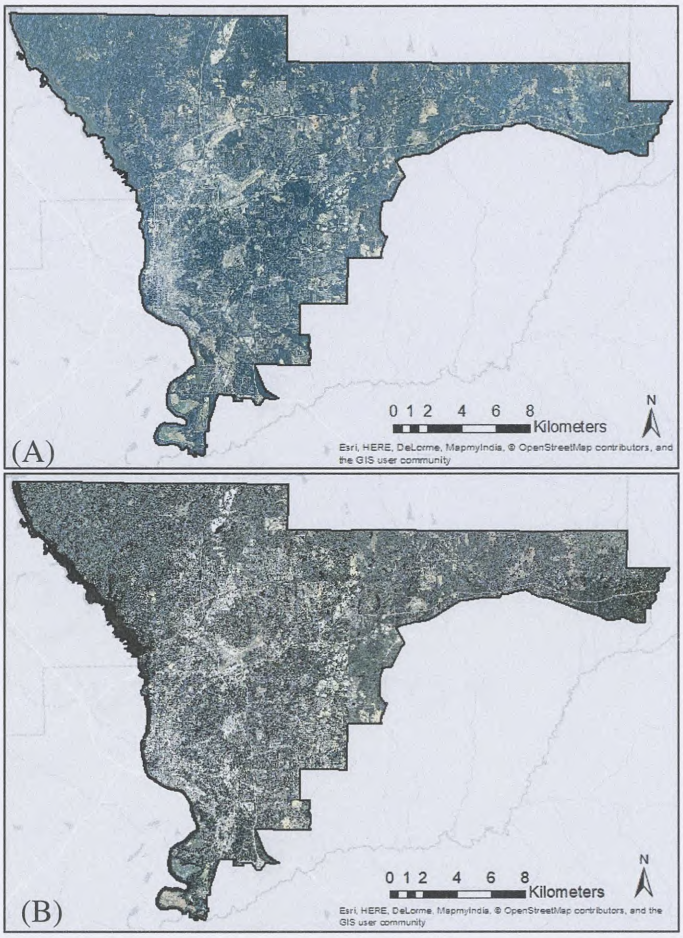


Figure 2. City of Columbus natural-color image A) 2005 2-meter spatial resolution, 3-band NAIP and B) 2010 1-meter spatial resolution, 4-band NAIP.

Imagery classification was conducted using ESRI ArcGIS 10 software. NAD 1983 State Plane Georgia West FIPS 1002 Feet was used as the projected coordinate system as requested by the city of Columbus GIS Division. The city service boundary shapefile was used to clip Fort Benning from the imagery. Imagery was gathered at different times of day and on different days. The 2010 imagery was flown between two separate months. As a result, shadows, which

complicate classification, are at different angles in different sections. Recognizing flight pattern reduces this potential classification error. Quarter quadsacre closely followed the flight pattern used to gain the imagery. For this reason, the clipped city image was split using the DOQQ shapefiles to reduce classification error. The 2010 imagery was provided in 25 DOQQ tiles, so analyzing each separately was the most effective analysis technique (Figure 3A). For the 2015 imagery, DOQQ shapefiles were combined into four large images to group based on similar topographical sections (e.g. urban versus forest) and to reduce processing time (Figure 3B). The 2005 imagery, as received, was not cleanly mosaiced with north-south alignment issues across the image (Figure 3C highlights this issue). To reduce error, this imagery was cut along these mosaiced sections and analyzed in 10 sections (Figure 3D).

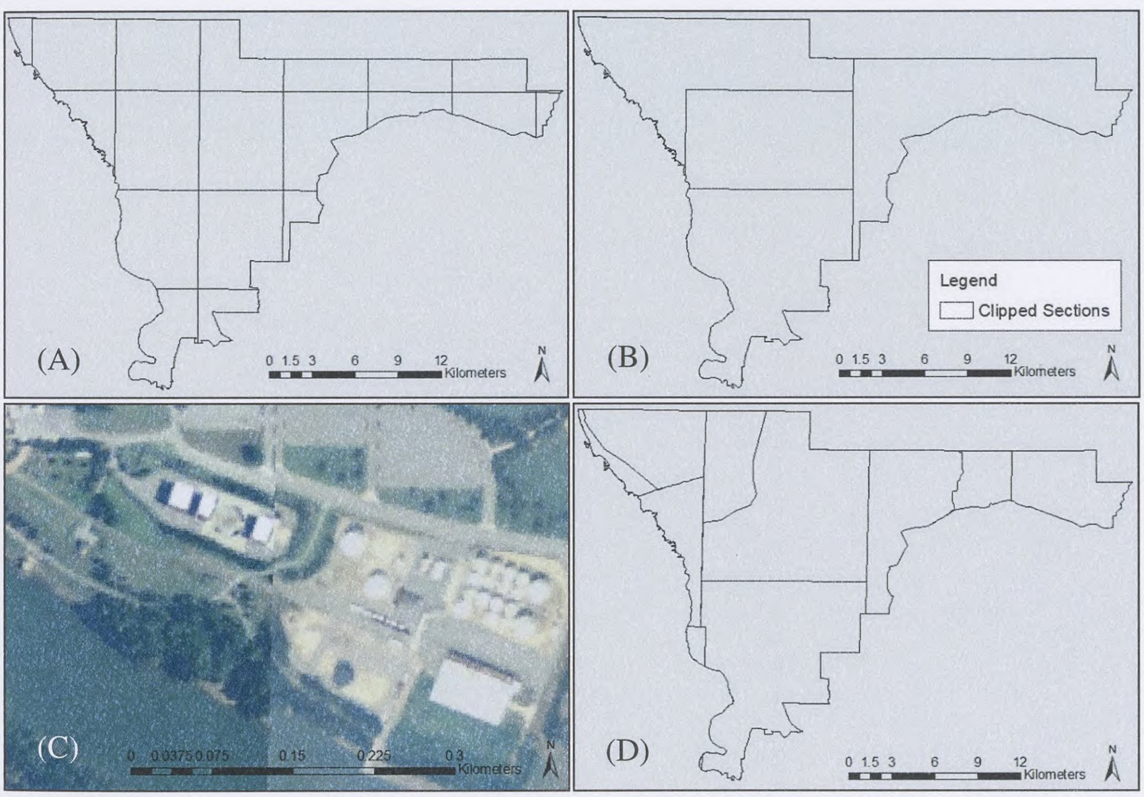


Figure 3. A) 2005 NAIP Columbus natural-color image showing an area of misalignment. The sections used to analyze B) 2005, C) 2010, and D) 2015 NAIP imagery.

1.2.3 Tree Canopy Image Classification - For larger areas that an analyst is not fully acquainted with, performing unsupervised classification can reduce error (Rozenstein & Karnieli, 2011). Therefore, for each section of the NAIP imagery, an unsupervised iso cluster classification process was conducted clustering the image bands (3-band for 2005, 4-bands for 2010 and 2015) into 40 classes. The 40 classes were visually interpreted and assigned labels of tree or non-tree (see Appendix A for iso cluster values by year). Postprocessing procedures involved mosaicing the classified sections into one raster of the whole city. The Majority Filter and Boundary Clean tools were used to clean the image by filling in areas of no data and smoothing the edges of tree and non-tree clusters (Keranen & Kolvoord, 2014). This approach yielded three classified thematic maps spatially showing tree canopy across Columbus, Georgia, in 2005, 2010, and 2015.

1.2.4 Classification Accuracy Analysis – A simple random sampling scheme with a sample size of 500 reference points for each year (i.e. 1,500 total points) was used to assess accuracy. Using multinomial probability theory, the following equation was used to determine sample size:

$$\mathrm{N} = \frac{B\pi_i(1-\pi_i)}{b_i^2},$$

where B is the upper α/k percentile of chi square distribution with 1 degree of freedom, k is number of classes (2), α is acceptable error (0.05), π_i is the proportion of trees in the classification (0.52), and b_i is confidence interval and precision (0.05). The multinomial model and simple random sampling satisfy assumptions of the kappa statistic (K-hat), which is used to calculate the significance of the error matrix table generated during the accuracy assessment (Congalton, 1991). Using this method, 1,500 reference points (500 for each of the three thematic classification rasters being assessed) were randomly generated using the Create Radom Points

tool in ArcGIS (Figure 4). All three years were assessed at each point with a separate value applied for each year based on landcover type in that particular year. Assessing all 1,500 points for all three years increases sample size, which in turn increases confidence in the classifications (Dicks & Lo, 1990).

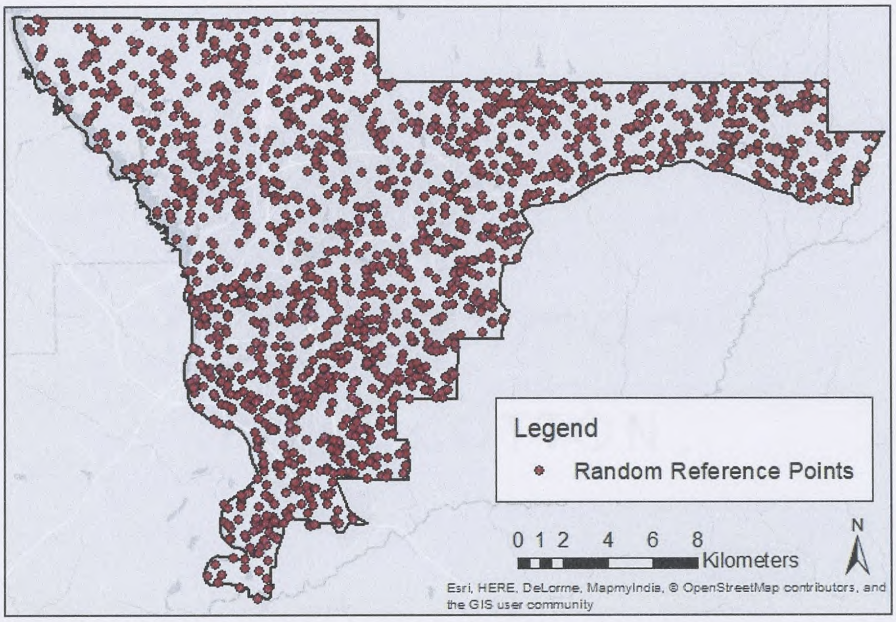


Figure 4. Position of 1,500 randomly generated reference points used to check accuracy of classified thematic maps with in the Columbus, Georgia, service region.

The reference imagery data used to access classification accuracy for 2005, 2010, and 2015 was Google Earth™ imagery. This tool was selected over actual ground truthing at the physical location because landcover changes rapidly. Google Earth™ serves as a good reference tool as the imagery within the tool has high-resolution and offers the historical images needed for assessment (Congalton, 1991; Olofsson et al., 2014). The history bar within Google Earth was utilized to access imagery from 1993 to 2017 for the region. The tool allows for rotating views, viewing imagery from different angles, and street view, which helped in determining tree versus non-tree when shadows were prominent. All years of imagery available (1993, 2003, 2005, 2006, 2007, 2009, 2010, 2011, 2012, 2014, 2016, 2017) were used to assess the accuracy of the

classification, especially the years before and after those of interest (i.e. 2005, 2010, 2015), as described in Olofsson et al. (2014).

All 1,500 reference points were manually assessed using Google Earth™ and given a value of 1 for tree and 2 for non-tree. The Extract Values to Points tool was used in ArcGIS to compare reference points to the classification raster for each of the three years (see Appendix 1, Table 4). Accuracy was then assessed using the error matrix table and corresponding Kappa coefficient (Congalton, 1991).

1.2.5 Spatial and Temporal Analysis – The Spatial Analysis tools in ArcGIS (Price, 2014) were used to determine percent tree canopy of the 53 census tracts using the 2015 US Census TIGER tract shapefile for the city of Columbus service region. A comparison of tree canopy change over time by tract was conducted and assessed by evaluating percent change by census tract between the three classified thematic maps. Changes within tracts were further evaluated to determine cause of any differences found, i.e. tree loss due to development and timber harvesting or gains due to tree plantings.

1.2.6 Air Quality Benefit Analysis - The i-Tree Tool was used in conjunction with the tree classification results to estimate urban tree canopy tree canopy air quality benefits. This tool applies average air pollutant removal rates and monetary values based on county level data. These county level rates were determined by combining tree canopy analysis, leaf area index (LAI) values, pollution removal rates by trees given local pollutant concentrations, and pollutant deposition rates based on local meteorological data (Nowak et al., 2014). The 2001 National Land Cover Database was used to determine tree cover and percent of cover that was evergreen, while the LAI values were found using the MODIS/Terra global Leaf Area Index product. Tree removal of air pollutants was determined using a statistical model that combined total tree cover,

evergreen percentage, LAI, local weather, and local air pollutant concentration data (Hirabayashi, 2014). Monetary value was estimated based on health incidences and associated costs that would be avoided with pollutant removal (Nowak et al., 2014). Table 1 contains the removal rates derived using this process for Columbus, Georgia.

Table 1. Tree air pollution annual removal rates and related monetary values for Columbus, Georgia, using i-Tree, developed by USDA Forest Service (Nowak et al., 2014).

Pollutants (Removed annually)	Removal Rate (tonnes/hectare-year)	Monetary Value ($/tonnes)
CO	0.0016	$463.91
NO_2	0.0105	$145.57
O_3	0.0560	$774.98
PM_{10} (2.5-10 μm)	0.0126	$2,068.42
$PM_{2.5}$ (<2.5 μm)	0.0036	$35,253.35
SO_2	0.0025	$40.25
CO_{2seq}	13.0	$39.00
CO_{2stor*}	282.5	$39.00

1.3 Results

1.3.1 Classification Accuracy Assessment – A 93 percent overall accuracy was found for the 2010 and 2015 classifications, while the 2005 classification had an accuracy of 89 percent (Table 2). The user and producer accuracy are the same for both tree and non-tree for the 2010 thematic map, so error was spread evenly between error of omission and commission (Table 2). The user accuracy (error of commission) for trees, i.e. the percent of trees correctly classified, is highest in the 2015 classification at 95 percent, with 2005 also being good at 92 percent. The kappa statistics for all three years is relatively high showing good agreement between reference data and thematic map data after accounting for agreement by chance. User accuracy for non-tree is 4 percent lower than tree for 2015 and 6 percent lower for 2005 classifications. The producer accuracy (error of omission) for trees, i.e. the percent of pixels correctly labelled as trees, is 3 percent lower for tree versus non-tree for the 2015 classification and 4 percent lower

for 2005. In summary, the 2015 and 2005 classifications represent actual referenced trees better than non-trees, while the percent of pixels correctly labelled as non-tree is higher.

Table 2. Error matrices for 2005, 2010, and 2015 classifications containing user and producer accuracy, k statistics (78, 86, and 87 percent respectively), and overall accuracy (89, 93, and 93 percent respectively) results.

	2015 Accuracy Assessment				**2010 Accuracy Assessment**				**2005 Accuracy Assessment**			
	Reference Data				Reference Data				Reference Data			
Thematic Map Data	Tree	Non-Tree	Map Total	User's Accuracy	Tree	Non-Tree	Map Total	User's Accuracy	Tree	Non-Tree	Map Total	User's Accuracy
Tree	751	36	787	95%	735	53	788	93%	716	62	778	92%
Non-Tree	64	649	713	91%	53	659	712	93%	103	619	722	86%
Reference Total	815	685	1500		788	712	1500		819	681	1500	
Procedure's Accuracy	92%	95%			93%	93%			87%	91%		
	Overall Accuracy = 93% K-hat = 87%				**Overall Accuracy = 93% K-hat = 86%**				**Overall Accuracy = 89% K-hat = 78%**			

1.3.2 Spatial and Temporal Dynamics of Tree Canopy Coverage – In 2015 and 2010, the city of Columbus tree canopy covered 52 percent of the area, equivalent to 19,815 and 19,809 ha (48,964 and 48,949 acres), respectively. In 2005, the tree canopy made up 53 percent of landcover, equivalent to 20,012 ha (49,453 acres).

In 2015 the tree canopy cover in the 53 census tracts ranged from 13 to 75 percent of land cover. The range was 10 to 75 percent in 2010 and 9 to 73 percent in 2005 (Figures 5 and 6). While the overall canopy coverage for Columbus remained steady (2005-2015), the change over time within certain tracts and in certain areas of the city is notable (Figure 7). In 2005, 5 tracts had less than 20 percent canopy. This number dropped to 2 tracks with less than 20 percent canopy in 2015. The number of tracks with 20 to 39 percent canopy changed from 18 in 2005 to 26 in 2015. The tracts within the 40 to 59 percent canopy range decreased from 24 in 2005 to 21 in 2015. The tracks with the highest canopy (60 percent and over) decreased from 6 in 2005 to 4

in 2015 (Figure 6, see Appendix A for Table 5 summarizing by tract tree canopy and Table 6 by tract air quality benefits).

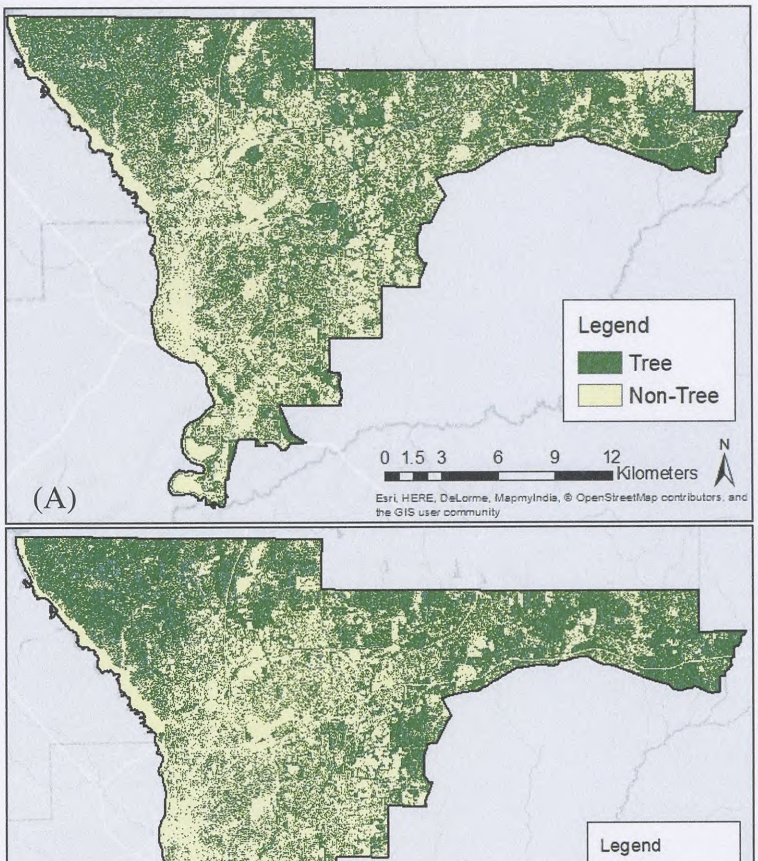


Figure 5. City of Columbus thematic tree canopy map for A) 2005, B) 2010, and C) 2015.

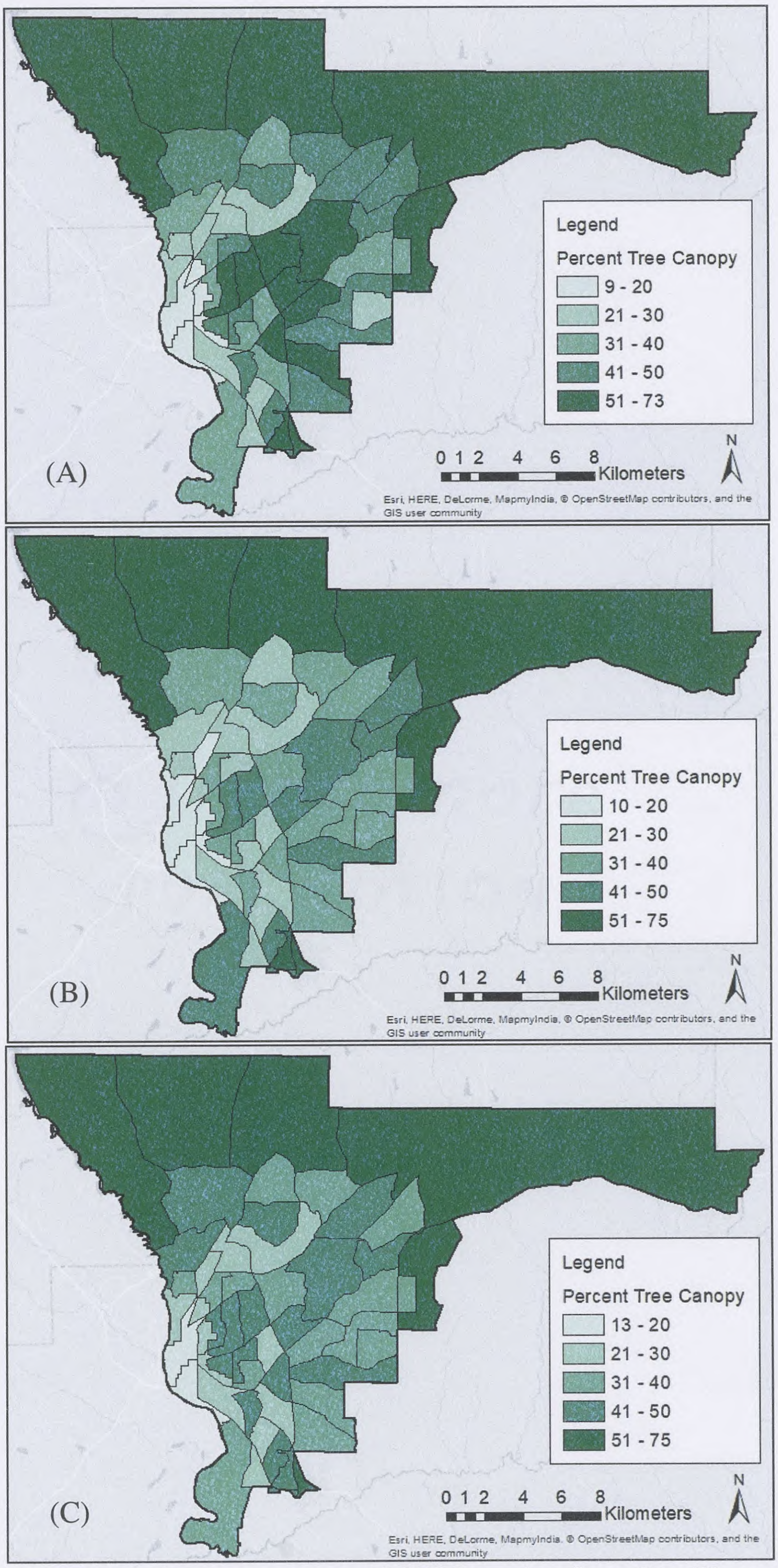


Figure 6. Percent tree canopy by census tract: A) 2005 ranging from 9 to 73 percent UTC, B) 2010 ranging from 10 to 75 percent UTC, and C) 2015 ranging from 13 to 75 percent UTC.

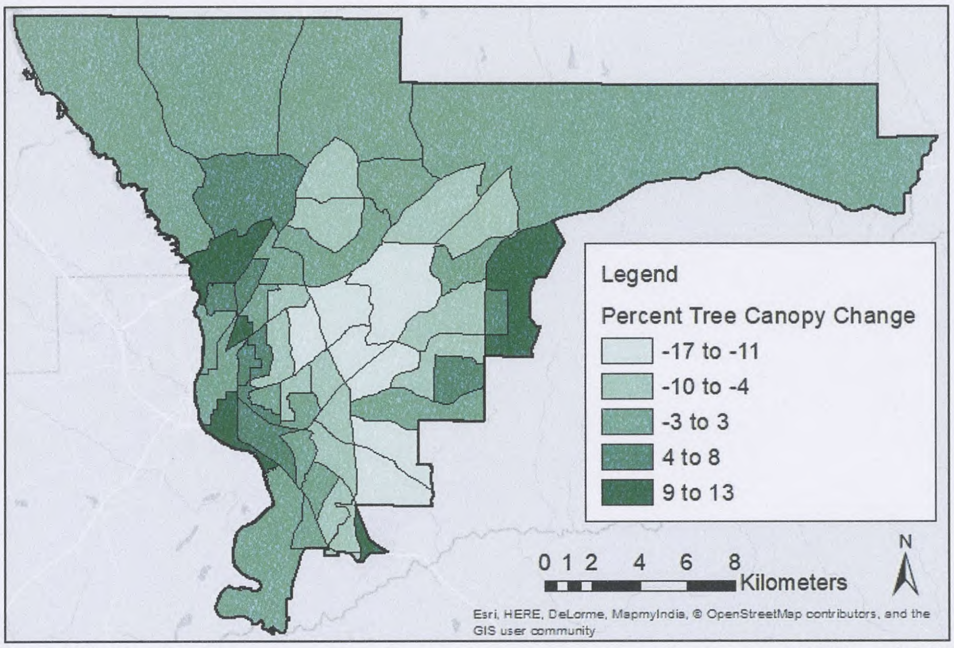


Figure 7. City of Columbus tree canopy change by census tract between 2005 and 2015. Light green represents losses (22 tracts) and dark green represents gains (13 tracts) in canopy over the ten-year period.

1.3.3 Air Quality Benefit Analysis - Approximately, $4 million in health-related savings can be attributed to the removal of 1,700 tonnes (1,900 tons) of pollutants annually by trees (Table 3). $10 million of savings is due to 256,000 tonnes (282,000 tons) of carbon dioxide sequestered annually by Columbus trees (Table 4). Additionally, the 20,000 hectares (49,000 acres) of trees store 5.6 million tonnes (6.2 million tons) of carbon dioxide valued at $218 million (i.e. this is a long-term value).

Table 3. Columbus, Georgia, tree air quality benefits using USDA Forest Service i-Tree tool (Nowak et al., 2014).

Pollutants (Removed annually)	2015 Columbus Removal (tonnes/yr)	2015 Monetary Value ($/yr)	2010 Columbus Removal (tonnes/yr)	2010 Monetary Value ($/yr)	2005 Columbus Removal (tonnes/yr)	2005 Monetary Value ($/yr)
CO	31	$14,394	31	$14,389	31	$14,537
NO_2	209	$30,449	209	$30,440	211	$30,753
O_3	1106	$857,419	1106	$857,157	1117	$865,982
PM_{10} (2.5-10 μm)	248	$512,863	248	$512,706	250	$517,985
$PM_{2.5}$ (< 2.5 μm)	73	$2,564,998	73	$2,564,212	73	$2,590,614
SO_2	50	$1,999	50	$1,998	50	$2,019
Total Criteria Air Pollutant Removal	1,717	$3,982,122	1,717	$3,980,902	1,732	$4,021,891

Table 4. Columbus, Georgia, tree carbon dioxide sequestration and storage using USDA Forest Service i-Tree tool (Nowak et al., 2014).

Pollutants (Removed annually)	2015 Columbus Removal (tonnes/yr)	2015 Monetary Value ($/yr)	2010 Columbus Removal (tonnes/yr)	2010 Monetary Value ($/yr)	2005 Columbus Removal (tonnes/yr)	2005 Monetary Value ($/yr)
CO_{2seq}	256,300	$9,995,634	256,221	$9,992,572	258,860	$10,095,460
CO_{2stor}	5,583,416	$217,751,913	5,581,706	$217,685,205	5,639,177	$219,926,585

Air quality benefits across Columbus are best visualized by applying the removal rates to trees within each census tract (Figures 8 and 9). Trees in the northern portion of the city (tracks 101.07, 108.02, 102.03, 102.01, and 103.01) remove the largest tonnage of air pollutants per unit area. The trees in the downtown areas (the southwestern portion of the city) remove the least, with the midtown trees removing slightly higher amounts of pollutants. This trend matches the tree canopy across Columbus. Air pollution removal rates through the i-Tree Tool are calculated based on tree coverage.

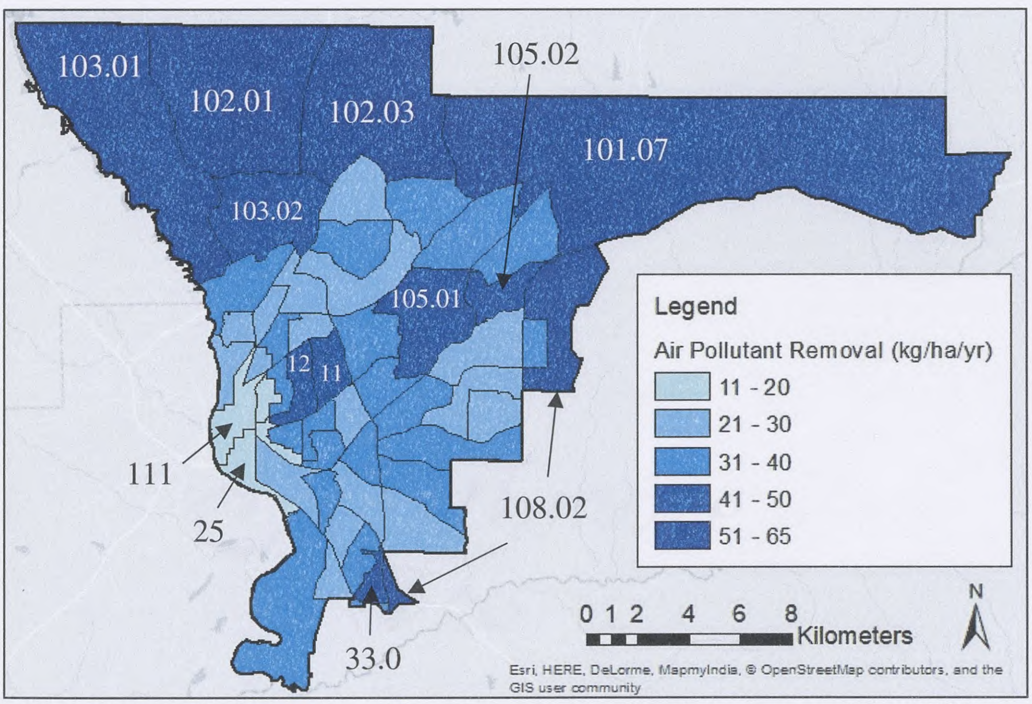


Figure 8. Annual air pollution removal by census tract. Numbers (except 11 and 25) represent tracts with largest air pollution removal. Numbers 111 and 25 represent tracts with lowest pollution removal.

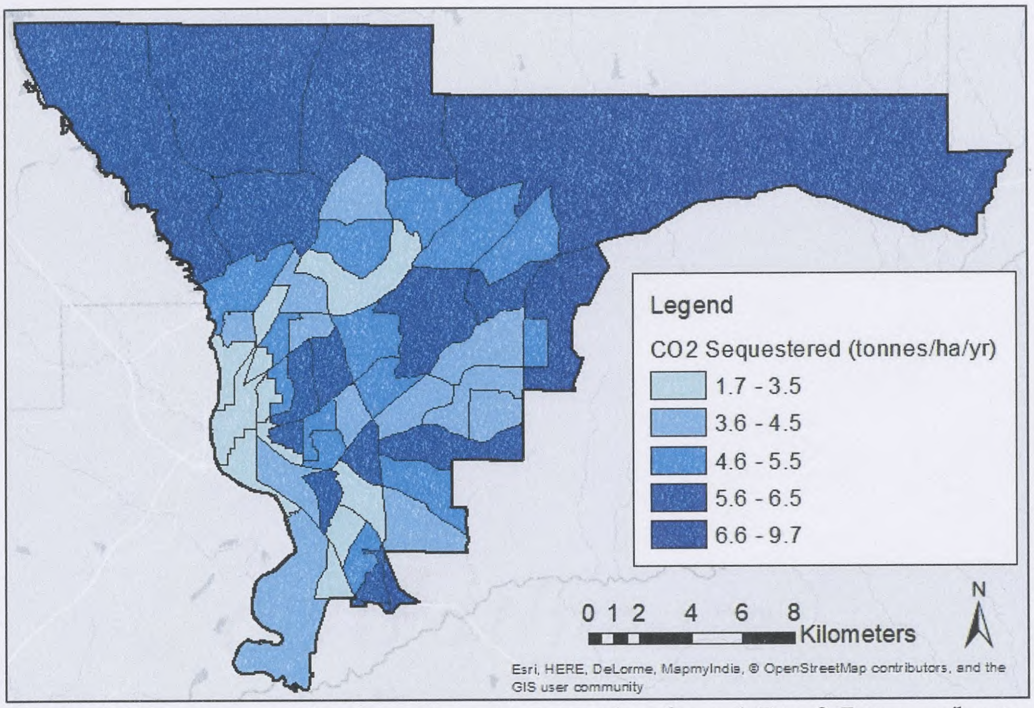


Figure 9. Annual CO_2 sequestration by census tract ranging from 1.7 to 9.7 tonnes/hectare. Dark blue represents tracts with largest and light blue the least sequestration.

1.4 Discussion

1.4.1 Classification Accuracy Assessment – The lower accuracy seen in the 2005 data is due to the NAIP imagery having a spatial resolution of 2-meters and only 3-bands. Using 4-band imagery allows for greater distinction between water and vegetation, both of which can have a greenish hue especially when water has high nutrient content. Water is not reflective, but rather absorbs EM radiation in the near-infrared (band 4) while healthy vegetation is very reflective in this band (Fox, 2015). Additionally, the 2005 iso cluster rasters had lower resolution with larger clusters covering multiple landcover types, i.e. trees, buildings, and road were in one clustered pixel group. Given these constraints, the 2005 NAIP imagery was more difficult to analyze, which increased error.

The main source of error in the 2010 and 2015 classification rasters was due to performing an iso cluster unsupervised classification. Distinguishing shadows between those

concealing trees and those concealing non-tree landcover was difficult as these were combined in at least one iso cluster class for most clipped sections. Often iso cluster classes combined tree and non-tree features. For example, tree and non-tree vegetation share at least one or two iso cluster classes in each clipped section because spectral signatures for grass, bushes, and trees can overlap. Reclassifying these classes as only tree or non-tree increased error. Unfortunately, all classification processes have error whether computer generated, as with unsupervised classification, or human error, as seen with the supervised classification process due to lack of familiarity with the region being analyzed (Rozenstein & Karnieli, 2011). The accuracy of the 2010 and 2015 classifications is good compared with other classifications of NAIP imagery found in literature (Davies et al., 2010; Li et al., 2014; Moskal, Styers, & Halabisky, 2011). Also of note, the 2010 NAIP imagery had added error with clouds covering a field of trees in the northeast portion of the image.

1.4.2 Spatial and Temporal Dynamics of Tree Canopy Coverage – The ideal canopy cover for an urban area as stated by the American Forests Urban Forest Program is 40 to 60 percent for forested states like Georgia (Leahy, 2017). The city of Columbus falls well within this range when the city is considered as a whole, possessing 52 percent canopy cover between 2005 to 2015. The 200-hectare difference between 2010, 2015 and 2005 is negligible when classification error is considered. While the aggregate canopy cover did not change over that time period, the canopy within the 53 census tracts did change over time. These results highlight the city's recent development and forestry practices.

The greatest loss in canopy over the ten-year period occurred in the lower middle census tracts (Figure 7). Based on interpretations of classification changes over time and changes seen during the error check, there are two main reasons for tree loss: development and removal of

residential trees. The majority of the UTC loss seen over time was associated with development. In many cases, trees were cleared between 2005 and 2010, but buildings and pavement were not in place until after 2010. These areas of development have lower canopy cover to start with, and, therefore, the tree loss leaves a greater impression than areas with greater percent canopy. The increase in impervious surfaces in these areas affects to air quality too, as roads and businesses increase vehicle traffic to these areas. Ornamental trees are often planted at new businesses and shopping areas, but these trees are smaller than the mature trees removed during construction. Ornamental trees, like crape myrtles (*Lagerstroemia indica L.*), have small leaf area indexes and mature tree heights, which makes them poorly suited for reducing air pollutants (McPherson, Simpson, Peper, & Xiao, 1999; Yang, Chang, & Yan, 2015).

Census tract 25, the area between the Chattahoochee river and south of Highway 280 containing the Columbus Civic Center (Figure 8), had the second smallest tree canopy for all three years. This tract experienced a 9 percent gain in tree canopy between 2005 and 2015 because the city arborist and local tree organizations focused on tree plantings in this area (S. Jones, personal communication, October 27, 2017). Based on a thorough examination of the area and discussions with the city arborist, little can be done to further improve tree canopy in this area unless businesses get involved, even with a canopy cover of only 18 percent in 2015. Much of the land is owned by the city in the form of public parks with ball fields and parking lots. The remainder of the tract is private property.

Other tree canopy gains over the ten-year period are due in large part to tree growth on forestry lands previously cleared for timber. This growth was evident in the northeast corner of Columbus (Figure 5). Another noteworthy area is the northeast tract, known as Midland (tract 101.07). While this area has experienced little overall change in canopy between 2005 and 2015,

a lot has changed in canopy location across this large census tract. The most eastern portion of the tract has many pine tree farms that were harvested around 2005 and have since been replanted. The western to middle portion of this tract has experienced a lot of development with the expansion of neighborhoods and businesses at the expense of tree canopy. While the forest regrowth offset the losses due to development, another timber harvest would reduce tree canopy for this area and the city as a whole. Due in part to the city tree ordinance enacted in 2002, Columbus maintained marginal loss of trees despite large gains in impervious surfaces. Key to the reduction of tree loss is the mandate that requires new business developments plant trees in parking lots.

When adding trees to an urban environment, planning often focuses on location and types of trees to best provide the ecosystem services trees offer. Attention should be given to utilizing as many of tree benefits as possible in addition to air pollution reduction, like water management, social and recreational values, and noise reduction (Miller, Hauer, & Werner, 2015; Grey, 1996; Jim, 2004). City owned property, i.e. parks, city buildings, monuments, cemeteries, and right of ways, lacking tree coverage is the first priority for planting locations (Grey, 1996). Columbus has done a good job of managing trees in many of these areas, but downtown municipal buildings lack appreciable tree canopy. In the Columbus downtown area, cemeteries, the medical center, and businesses comprise the land available for planting trees. Increasing trees in these vegetation sparse areas will involve educating businesses on the value of trees.

When compared with 5 other counties and their associated major cities in the Southeastern United States, Muscogee County has the best canopy cover (Table 5). However, the urban portion of Columbus only has more canopy cover than Montgomery, Alabama. As

Chatham is located on Georgia's coast, it's land cover is 32 percent water, which reduces land available for tree plantings (Plan-It Geo, 2015). The five counties viewed for comparison, except for Chatham, Georgia, have the same trend as Muscogee County: they all possess greater canopy cover than their major cities. This alludes to the idea that air pollutants are most likely being produced in areas with lower numbers of trees to reduce the pollution. Charlotte, North Carolina, has similar population density over land area as Columbus, but Charlotte has a greater canopy cover as compared to the urban portion of Columbus. This suggests that Columbus can improve its tree canopy in the developed portions of the city.

Table 5. U.S. Southeastern counties' populations, areas, and canopy coverage.

County (Major City)	2010 County Population	City % of County Population	City Population/ Hectare	City % of County Land Area	County % Canopy	City % Canopy	Study Year
Muscogee (Columbus), GA	189,885	*84*	*8.9*	*47*	52	*37*	2015
Mechlenburg (Charlotte), NC[1]	919,628	80	9.6	53	50	46	2008
Guilford (Greensboro), NC[2]	488,406	55	7.9	20	50	38	2007
Chatham (Savannah), GA[3]	265,128	52	5.2	21	36	44	2013
Tri-county area (Montgomery), AL[4]	363,597	57	5.2	8	47	34	2002
Hamilton (Chattanooga), TN[5]	336,463	50	4.5	25	N/A	51	2008

1 American Forests, 2010b; 2 Cusimano, Bardsley, Ashton, & Hill, 2009; 3 Plan-It Geo, 2015;
4 American Forests, 2004; 5 American Forests, 2010a

1.4.3 Air Quality Benefit Analysis - Spatially, the city tree canopy differs greatly from north to south. The census tracts (101.07, 102.03, 102.01, and 103.03) north of highway 80 and tract 108.02 (second most eastern tract below 101.07) are considered the northern portion of the city. These four and tract 108.02 (previously Fort Benning land) are not as developed as the rest of the city, containing mainly forest and agriculture landcover. These five tracts comprise 53 percent of the area for the city of Columbus. Only 16 percent of the Columbus population

resides in this northern portion of the city. The remaining 48 tracts make up the other 47 percent of the land in the southern portion of the municipality. This distinction, north versus south, separates the mainly urban, developed portion of Columbus (south) from the agricultural, rural portion (north).

The north portion of Columbus contains two-thirds the city tree canopy. Not surprisingly these 5 tracts experience the most air quality benefits of trees (1,141 tonnes of air pollutant removal, 170,000 tonnes CO_2 sequestered annually). If these 5 northern census tracks were removed from Columbus (leaving the urbanized portion of the city), it would only have 37 percent tree canopy capable of removing an estimated 576 tonnes of air pollutants and sequestering 86,000 tonnes of CO_2 annually. Many of the city's shopping centers and businesses exist in the south central portion of the city, so most residents must travel within the southern section. Therefore, the majority of the air pollutants are being produced (via vehicles and businesses) in the portion of the city with the least number of trees.

Urban forest management involves diversifying types of trees planted and selecting trees that can remain stable, improve air quality, and not emit high amounts of volatile organic carbon (VOC). VOCs contribute to air pollution and can lead to higher particulate concentrations (Miller et al., 2015). The best tree species to reduce pollution are typically unpopular trees to use in street and residential planting (Yang et al., 2015; Simpson & McPherson, 2011; Curtis et al., 2014; Benjamin, Sudol, Bloch, & Winer, 1996). Conversely, popular trees, like oaks, offer great air pollutant reduction but also emit high VOCs during spring and summer seasons (Curtis et al., 2014; Bolund & Hunhammar, 1999). This points to the need to diversify the types of trees planted across cities, prioritizing the species with the best overall performance.

The methods used here to quantify tree canopy coverage and its associated air quality benefits have limitations. Comparing city canopy cover using aerial imagery at five-year intervals may not provide adequate time to detect differences at a city-wide scale. Analysis every ten years, is better for tracking these changes. However, technological advancements are expected during a time period of ten-years, which makes comparable imagery difficult. NAIP imagery improved over the 10 years used in this analysis, from 3-band, 2 m resolution in 2005 to 4-band, 1 m resolution in 2010. Starting in 2017, three states had NAIP imagery available with 50 cm resolution. It is likely that this higher resolution imagery will be available for all states soon (USDA, 2017). Satellite imagery is also improving, offering better resolution and more bands than NAIP (WorldView-2: 0.5m resolution with 8 bands). However, these satellite images are not free, like NAIP.

Meneguzzo, Liknes, and Nelson (2013) found the unsupervised approach to NAIP imagery classification overestimates tree clusters as compared with object based image analysis (OBIA) and better reflects photo-interpreted results compared to ground-based or bottom-up approaches. Ground surveying trees in a city on a block by block approach is often the next step after quantifying canopy using high spectral imagery (Miller et al., 2015). Tree surveys are helpful in identifying tree health, height, and type, which better assists in planning at a street level.

Since the i-Tree Tool is a first-order assessment of air pollutant removal associated with trees, it is not possible to estimate the degree of accuracy and variability associated with its predictions. The developers of i-Tree acknowledge that there are limitations in using this method (Nowak et al., 2014). Removal rates are calculated in part based on air pollution concentrations and meteorological data, which are gathered at county and regional levels. For

example, SO_2, $PM_{2.5}$, O_3, and meteorological data were retrieved from data collected at the Columbus Airport (AQS Site ID: 13-215-0008), which is centrally located in Muscogee County. PM_{10} data was collected at Cusseta Road Elementary school (AQS Site ID: 13-215-0011) in south Columbus. NO_2 and CO data were collected near Atlanta, Georgia, (AQS Site ID: 13-089-0002) approximately 145 km away from Columbus (EPA, 2015). Thus, the removal rates for SO_2, $PM_{2.5}$, PM_{10} and O_3 are better applied at the city scale, given the data used to determine these rates was obtained within Columbus, as compared to the removal rates for NO_2 and CO. Vehicles and energy production are main sources of NO_2 and CO emissions in urban settings (Girard, 2014). As Atlanta, Georgia, is more heavily populated with more vehicles than Columbus, Georgia, relying on NO_2 and CO data gathered in the Atlanta metropolitan area to create Columbus removal rates raises concerns. With fewer vehicles in Columbus, it is conceivable the pollution concentrations in the area are lower than the Atlanta area. Therefore, removal rates for these two air pollutants by trees in the Columbus area are likely overestimated. In this study, pollutant removal rates were applied at the census tract level. While useful for highlighting variation in the removal of air pollutants across the city, this approach may not accurately represent pollutant attenuation. As air pollution is generated locally, the trees in the northern portion of the city may not be removing air pollutants at the rates estimated if the air pollution does not exist in these areas.

In addition to the limitations caused by the lack of air pollutant concentration data, too few studies quantify tree reductions of air pollutants (Pataki et al., 2011; Setälä et al., 2013). This scarcity of data is a noteworthy drawback to the i-Tree model. Additionally, the $PM_{2.5}$ concentrations removed by trees may be insignificant compared to the levels in the air (Witlow, 2009).

Over half the monetary savings of the five criterion pollutants found using i-Tree are attributed to $PM_{2.5}$ removal (4 percent of the 1,700 tonnes of air pollutants removed annually). $PM_{2.5}$ health concerns have been well researched (Sarnat, Schwartz, & Suh, 2001; Pope III et al., 2002; Schlesinger et al., 2006; Fann et al., 2012), but the tie between trees interactions with PM2.5 and the credited health benefits has not been well researched (Pataki et al., 2011). Estimates from the i-Tree model suggest that Columbus trees offer $4 million in health savings. This estimate may not be an accurate assessment.

As an example, consider $PM_{2.5}$ and its complex interactions with trees. This relationship cannot fully be captured in a simple removal rate, even if the rate was generated using Muscogee County specific data. Other air pollutants such as O_3, NO_2, SO_2, and CO (being gaseous) have simpler relationships with trees because they are removed from the atmosphere by leaf stomata. In contrast, temperature, wind direction and wind speed alter $PM_{2.5}$ deposition and resuspension (Hemond & Fechner, 2014; Nowak et al., 2014; Tong, Whitlow, MacRae, Landers, & Harada, 2015). County $PM_{2.5}$ removal rates vary in the i-Tree model and are positive or negative (increases in $PM_{2.5}$) depending on county wind and precipitation conditions (Hirabayashi, 2014). While $PM_{2.5}$ rates used in the model come from county specific data, the interaction with trees and $PM_{2.5}$ is clearly complicated. This complex interaction between $PM_{2.5}$ and local tree canopy conditions requires additional research.

While the approach employed in this research to quantify trees' air quality services has limitations, the benefit of this top-down approach in locating and determining change in canopy over time allows for city planners to develop tree plans that can improve local environmental conditions. Conducting a thorough tree benefit analysis at the street level would be ideal, but, access, time, and funding are large hinderances to this endeavor. A standard model, like i-Tree,

provides city planners with information that can be used to gain support and funding for future tree plantings. As long as caution is taken by weighing the approximated air quality reductions and monetary values in light of the model's restrictions, this approach is helpful to start conversations relating to vegetation planning at the city level.

CHAPTER 2 – TREE ARRANGEMENT PARTICULATE MATTER TESTS

2.1 Introduction

Air pollution reduction benefits by trees in urban areas have been linked to health improvements (Beckett, Freer-Smith, & Taylor, 2000; Tiwary, 2009; Nowak et al., 2014). The air quality benefits of trees for gaseous air pollutants is a simpler relationship compared to particulate pollutants because trees remove gaseous pollutants from the atmosphere through leaf stomata. In contract, trees are a temporary resting location for fine particulate matter, $PM_{2.5}$. Tree interactions with particulates is dependent on weather conditions such as temperature, relative humidity, wind direction and wind speed all of which alter $PM_{2.5}$ deposition and resuspension (Hemond & Fechner, 2014; Nowak et al., 2014; Tong, Whitlow, MacRae, Landers, & Harada, 2015; Cai et al., 2017). While studies have been conducted to better define this relationship, studies often discuss the need for testing across regional conditions (Ortolani & Vitale, 2016; Nowak & Greenfield, 2008; Nowak et al., 2014; Witlow, 2009). The complex interactions between trees and particulates warrants additional examination.

2.1.1 Particulate Matter and Trees - Particulate matter (PM) is among the six criteria air pollutants monitored by state agencies and regulated by the U.S. Environmental Protection Agency (EPA) under the National Ambient Air Quality Standards (NAAQS) as part of the Clean Air Act (Girard, 2014). PM is categorized by aerodynamic diameter into coarse, PM10 – 2.5 to 10 μm in diameter, and fine particles, PM2.5 - 2.5 μm or smaller in diameter. The residence time of PM10 is minutes to hours, being removed from the air due to gravitational settling. As a result, PM10 travels less than 100 km. PM2.5 has a residence time of days to weeks. It is often removed through dry deposition and rain and travels 100s to 1000s of kilometers (Wilson & Spengler, 1996). In interactions with trees, PM2.5 levels on leaves are lower than PM10 due to

gravitation deposition properties (Beckett, Freer-Smith, & Taylor, 2000; Freer-Smith, 2005; Sæbø et al., 2012). Fine particulates are solid/liquid aerosols created through anthropogenic activities e.g., fossil fuel combustion, wildfires, steel making, and natural processes e.g., sea spray, pollen, vegetation releasing volatile organic compounds (Hemond & Fechner, 2014; Girard, 2014). These microscopic particles are most distressing for health reasons as inhaling these aerosols can cause respiratory and cardiovascular complications (Sarnat, Schwartz, & Suh, 2001; Pope III et al., 2002; Schlesinger et al., 2006). Inhalation of PM2.5 caused an estimated 130,000 deaths in the U.S. in 2005. For comparison, 4,700 deaths were attributed to ozone exposure in the same year (Fann et al., 2012).

Field studies monitoring $PM_{2.5}$ within and near tree buffers report varying results. Several small-scale experiments in the New York City area indicate that tree buffers limit $PM_{2.5}$ dispersion causing concentrations to be elevated in close proximity downwind from tree lines, while $PM_{2.5}$ concentrations quickly decrease in open areas (Tong et al., 2015). The New York City study and two other studies conducted in and near Beijing found $PM_{2.5}$ concentrations are higher within dense tree canopy buffer or forests as compared with open areas (Tong et al., 2015; Liu, Yu, & Zhang, 2015; Chen et al., 2015). A Detroit, Michigan field study found vegetation barriers caused particulates to decrease more gradually beyond the tree stand than open areas (Brantley, Hagler, Deshmukh, & Baldauf, 2014). Witlow (2013) found that particulates increased with distance behind tree stands. Another study reported that tree buffers decreased particulate matter beyond tree stands when the wind is from the direction of the road (Baldauf et al., 2008). These reported results were conducted across different weather conditions in various locations, which further points to the need for site specific analysis of tree fine particulate air quality benefits.

The EPA has a guide for designing vegetation barriers along roadways in order to reduce air pollution and recommends denser tree lines to reduce air flow and stop pollutants near the street (Baldauf, 2016). In recent years, studies have been conducted in various tree configurations. Most studies, discussed above, indicate higher $PM_{2.5}$ concentrations exist within denser canopies (Tong et al. 2015; Whitlow, 2013; Tong, Chen et al. 2015). One study modelled the impact of air pollutant reduction among six tree designs finding dense tree buffers most effective (Baldauf, Isakov, Deshmukh, & Zhang, 2016). A few studies have modelled the tunnel effect created by trees lining either side of the street, which traps pollutants between the tree lines increasing concentrations (Gromke, 2011; Cai et al., 2017). These studies investigated the trees near roadsides, concentrating on the reduction of vehicle produced pollutants. Vehicles are a main particulate pollution sources in cities, but other sources like restaurants, prescribed burns, and utility companies can also contribute to $PM_{2.5}$ concentrations (Zheng et al., 2002). Additional field studies are needed to better understand the relationships between urban tree stand arrangements and $PM_{2.5}$ concentrations, especially accounting for local $PM_{2.5}$ sources and atmospheric conditions.

2.1.2 $PM_{2.5}$ Instrumentation - Fine particulate matter as regulated by the EPA is monitored by states using in situ continuous monitors that are accurate and expensive equipment, e.g, the Tapered Element Oscillating Microbalance (TEOM) and *b*-attenuation monitoring (BAM) analyzers (EPA, 2013). These monitors are located in larger cities across the U.S. (EPA, 2015), and are designed to measure regional PM levels. Air pollution across cities is heterogeneous, depending on localized interactions of $PM_{2.5}$, weather, and vegetation, and small portable sensors can be beneficial in identifying areas of focus and concern. Low-cost, portable PM sensors can be used to bridge the gap in knowledge between regional particulate data and

neighborhood level exposure to pollutants. However, caution should be taken when using these portable devices due to accuracy and reliability concerns (Jiao et al., 2016; Lewis & Edwards, 2016; Rai et al., 2017; Snyder et al., 2013; Wang et al., 2015; Manikonda, Zíková, Hopke, & Ferro, 2016).

The EPA encourages cities to study air quality at several locations using a variety of sensors to assess local air quality conditions (EPA – Smart City Challenge, Green Cities project). With advances in sensor technology, people can monitor their local air quality by operating a personal, portable PM device. While not promoting specific equipment, the EPA has supported these efforts by providing agency research on portable PM devices and data regarding how individuals and communities can use these devices to facilitate urban planning (EPA – Air Sensor Toolbox).

The Community Air Sensor Network (CAIRSENSE) project was conducted by the EPA and Georgia Environmental Protection Department to assess the accuracy of a few of these low-cost particulate matter devices including the AirBeam. The AirBeam is a low-cost portable fine particulate matter sensor developed in 2013. In CAIRSENSE, three AirBeams were tested for 168 days and compared to federal equivalent method (FEM) monitors. The results indicated mid-level agreement ($r = 0.65\text{-}0.66$; Jiao et al., 2016). This result was comparable to another low-cost PM device, the Dylos ($r = 0.63\text{-}0.67$). Notably, CAIRSENSE found a strong association among the three AirBeam devices tested (e.g. $r = 0.99$; Jiao et al., 2016). Another recent study compared AirBeam performance to reference instruments in field tests and found similar results (AirBeams to each other: $r^2 = 0.99$, to GRIMM 11-R $r^2 = 0.66$ to 0.71; Mukherjee, Stanton, Graham, & Roberts, 2017). While the AirBeam has mid-level agreement to FEM, these devices have utility as portable field devices when conducting comparative studies.

2.1.3 Study Goals - This research project investigated the question of the relative relationship of $PM_{2.5}$ concentrations within varying tree canopy types versus adjacent open areas. The AirBeams provide a useful tool to address this question. Since the complex relationship between trees and particulate matter is dependent on local factors (e.g., particulate sources, weather conditions), this research presents an opportunity to test the efficacy of AirBeams in the field at different locations and under different atmospheric conditions. Thus, one question posed by this research is whether a portable, low-cost monitoring device (specifically AirBeams) can be used to effectively compare $PM_{2.5}$ among differing tree canopy configurations? Based on previous AirBeam studies (Jiao et al., 2016; Mukherjee et al., 2017), it is hypothesized that the devices will be sufficient for measuring relative relationships among tree canopy configurations, but they will not be accurate for quantifying actual $PM_{2.5}$ concentrations in the field. As such, the first goal of this research is to assess the field capabilities of the AirBeam.

The $PM_{2.5}$ concentrations within open areas will be compared to adjacent tree buffers composed in the following tree arrangements: dense tree buffer (width > 45 m), small tree line (width < 30 m), and U-shaped tree arrangement (Figure 10). The following question will be addressed in this approach: Do open areas near PM sources differ in $PM_{2.5}$ concentrations as compared with adjacent tree stands of various configurations? It is hypothesized the dense tree stands will have higher $PM_{2.5}$ concentrations than adjacent open areas, small tree line $PM_{2.5}$ concentrations will have no appreciable difference to adjacent open areas concentrations, and the U-shaped tree arrangements will have highest relative concentrations of $PM_{2.5}$ within the open areas adjacent to the trees. Columbus has average low wind speeds, $PM_{2.5}$ should be trapped by dense trees and disperse less in open areas along streets. Therefore, the primary goal of this

study is to examine the relationship between $PM_{2.5}$ and trees by investigating varying tree canopy configurations.

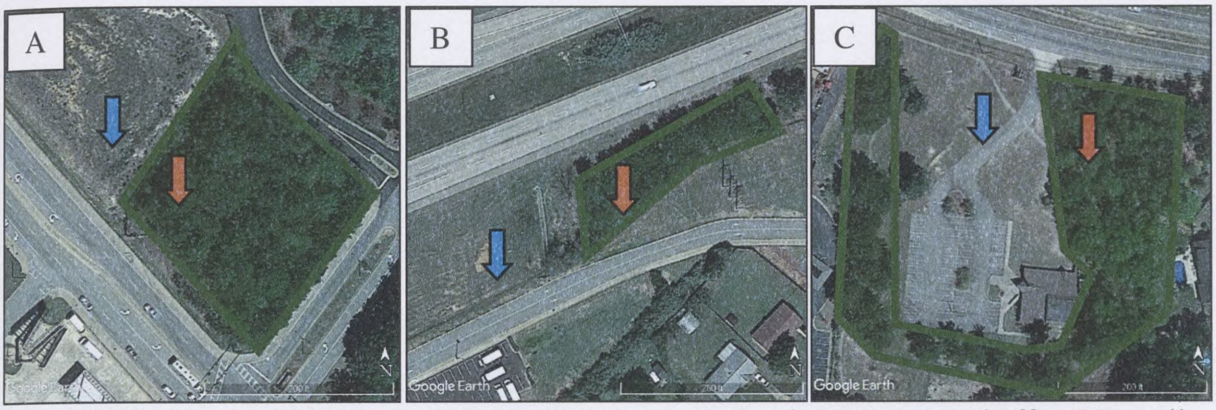


Figure 10. Picture of neighboring open areas and an example of A) dense tree buffer, B) small tree line, and C) U-shaped tree arrangement with examples of open (blue arrows) and tree (orange arrows) sample locations. (Images taken in 2017 via Google Earth™.)

2.2 Methods

***2.2.1 Study City Atmospheric Conditions and PM Sources* -** Columbus, Georgia, is located along the western border of the state (32° 29' 32" N, 84° 56' 25" W). The Fort Benning Army base is located to the southeast of the city. This city has an annual precipitation of 46 inches (NWS, 2017). Maximum monthly temperatures range from 57 °F to 92 °F and monthly minimum temperatures from 36 °F to 73 °F (lows in January and highs in July and August). Monthly relative humidity stays close to the annual mean of 65 percent, peaking at 71 percent in August with low of 62 percent in February and March (NCEI, 2017a). The city has mean winds speeds of 2.5 m/s with highest winds, 2.9 m/s, in the winter months. Mean wind direction is variable throughout the year, with the highest frequency of winds from the east (Figure 11; NCEI, 2017a). Climatological data used in this study was retrieved from the weather station located at the Columbus Metropolitan Airport (WBAN: 93842, Lat/Long 32.5161°, -84.9422°). The city's high annual precipitation and low annual wind speed should be conducive for $PM_{2.5}$ to

be trapped by trees and brought to the ground rather than resuspended into the air (Hirabayashi, 2014).

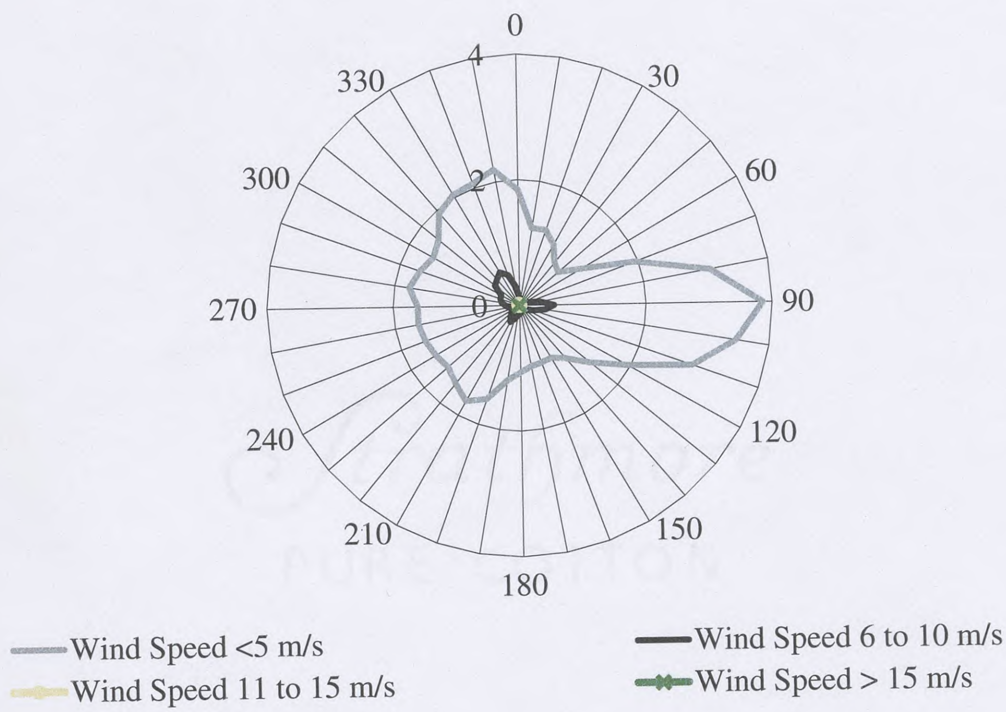


Figure 11. Columbus wind rose (data from 2007 to 2016) indicating highest frequency of winds from the east. Wind direction frequency is marked by the 2 and 4 percent circles.

Fort Benning is located to the southeast of Columbus. Many of the city's worst air quality days occur during controlled wildfire burns at Fort Benning. These burns increase $PM_{2.5}$ concentrations, among other pollutants. Several studies have monitored the air pollution at increasing distances around Fort Benning (Achtemeier, 2011; Baumann, 2005; Liu, 2010; Odman, 2012) because this pollution impacts the region. Like other cities, vehicles, residential wood burning, and meat cooking are main sources of fine particulate matter (Reff et al., 2009; Zheng, Cass, Schauer, & Edgerton, 2002), which have more localized influence as compared to the prescribed burns.

2.2.2 Instrumentation – In order to quantify $PM_{2.5}$, this research utilized the AirBeam (Figure 12A). This device employs a Shinyei PPD60PV particle sensor and Bluetooth to transmit data through a smart phone app called AirCasting (Android app, Figure 12B) or a website (aircasting.org/map). The AirBeam can record data while mobile or in fixed position. The AirBeam reports $PM_{2.5}$ ($\mu g\text{-}m^{-3}$), temperature (°F), percent relative humidity, and sound level (decibels) every second, minute, or hour in real time (Heimbinder & Besser, 2014). The Shinyei PPD60PV particle sensor uses the light scattering method to count particulates that cross the path of the encased infrared light (Figure 13). This particle sensor has a concentration measurement range of 0.5 to 300 $\mu g\text{-}m^{-3}$ (Shinyei Technology Co., Ltd). The AirBeam has an output resolution of 0.0001 $\mu g\text{-}m^{-3}$ when recording at 1-minute intervals and 0.01 $\mu g\text{-}m^{-3}$ when recording at 1-second intervals (Heimbinder & Besser, 2014). The data were sent from the app to email in comma-delimited format and converted to an Excel spreadsheet for analysis. The AirBeams each have a unique serial number recorded with the data to assist in quality assurance. Additionally, the devices and corresponding phones were labeled 1, 2, and 3 (AirBeam 001896105818, 001896105926, and 0018961061CE respectively) for easy identification in the field.

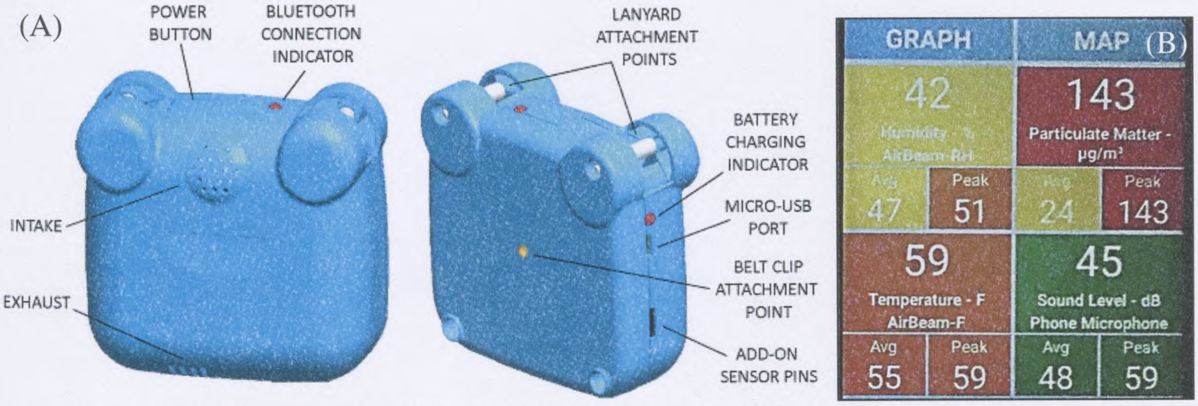


Figure 12. A) AirBeam diagram (Heimbinder & Besser, 2014) and B) smart phone app example.

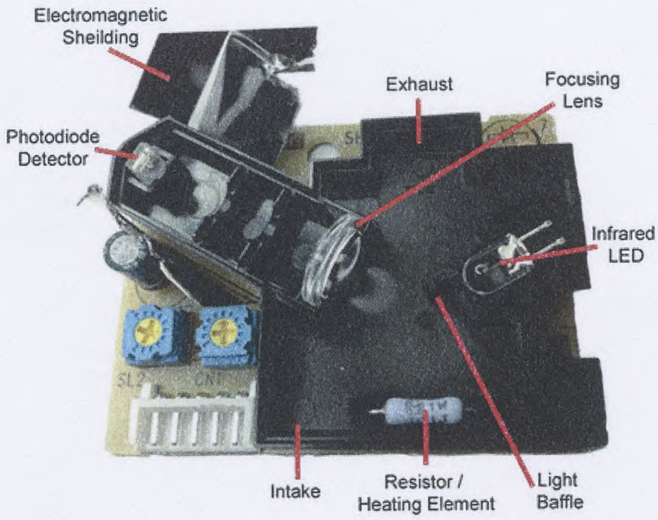


Figure 13. The inside of the Shinyei PPD60PV (Heimbinder, 2013).

Since temperature, relative humidity, wind speed and direction (Hemond & Fechner, 2014; Nowak et al., 2014; Tong et al., 2015; Tai, Mickley, & Jacob, 2010), precipitation, and change in pressure over time have been shown to account for 30 percent of the daily variability in $PM_{2.5}$ in Southeastern U.S. (Tai et al., 2010), a handheld Kestrel 4000 pocket weather meter (Nielsen-Kellerman, Nelson, PA) was used to collect the ambient temperature (accuracy: ±1 °C; resolution: 0.1 °C), relative humidity (accuracy: ±3%; resolution: 0.1%), and wind speed (accuracy: ±0.1 m/s; resolution: 0.1 m/s) aligned with wind direction at each site in ten-minute intervals. The wind direction was obtained using a compass by noting direction at maximum wind speed. Field tests were performed during periods of no precipitation to protect the AirBeam units.

2.2.3 AirBeam Equivalency Tests – Following best practices (Lodge, 1988) and EPA recommendations (Williams et al., 2004) any device used for monitoring air quality should be suitably calibrated. Based on the standard reference instrument method, the AirBeams were compared with the state's TEOM continuous monitor located at the Columbus airport. Due to instrumentation differences (the TEOM has omnidirectional intake, while the AirBeam units

have unidirectional intakes), data resolution differences (TEOM has 1-hour resolution and AirBeams have 1-minute resolution), and the limited lifespan of the AirBeams (2-hour battery life), it was determined intra-unit correction (through equivalency tests conducted prior to and during field testing) would be the best standardization method.

The three AirBeams were assessed for their equivalency across a range of $PM_{2.5}$ concentrations from 0 to 177 μg-m^{-3} before the start of the field tests. These units were assessed for equivalency at low ranges by running the devices over the course of three days in an undisturbed room, in which the room's HVAC vents were sealed and entry into the room was limited to conducting the test. The Austin Air HealthMate Plus® (an air purifier capable of removing particulates larger than 0.3 microns) was used to reduce particulate matter within the room after small levels of smoke were allowed into the room through a small opening in the window to compare response to stimuli over time. The three units were equal distance from the opening in the window and the air purifier.

A second indoor test was conducted to compare the units' response to high particulate concentrations. This test was performed by burning a 160 g carbon fiber vinyl ester specimen in a muffle furnace at 600 °C for 1 hour 47 minutes. The AirBeams were positioned in the fume hood 1 m above the furnace smoke stack. The fume hood was allowed to run prior to and during the burning of the carbon sample to ensure steady airflow. During this equivalency test, unit 3 disconnected from the phone app and did not record 22 minutes of data. These 22 minutes were removed from the statistical analysis for all units.

The first two tests were conducted in controlled indoor environments. The last equivalency test was conducted outdoors to assess response of the units to stimuli without the ability to control environmental factors. The AirBeams were set up outside equal distances and

downwind from an outdoor wood burning stove. Smoke was allowed to escape from the top of the stove for 5 minutes, and then the fire was squelched in the stove. The units collected data for 5 minutes before and after the smoke, and the data were assessed to determine if the units responded to the stimuli at the same time.

The Pearson product-moment correlation coefficient was computed between the three AirBeams and the state TEOM. Model II linear regression was used to assess the relationship among the three AirBeams for all equivalency tests combined. As with time-series data, autocorrelation was an issue in the results of all three equivalency tests. The appropriate lag was determined and autocorrelation corrected for each individual test (indoor test 1 lag = 21 min, indoor test 2 lag = 4 min, outdoor test 1 lag = 2 min) before using one-way analysis of variance (ANOVA) to compare the results of the three units.

2.2.4 AirBeam Temperature and Relative Humidity – The AirBeam's relative humidity and temperature sensors are good indicators to ensure the devices are not overheating or oversaturated. AirBeams are programmed to shut off at 100 percent humidity (Heimbinder & Besser, 2014) and the Shinyei PPD60PV performs best at temperatures of 0 to 45°C (Shinyei Technology Co., Ltd). Jiao et al. (2016) and Mukherjee et al. (2017) did not address the performance of the temperature and relative humidity sensors housed in the AirBeams. The output from these sensors were compared to Kestrel 4000 data obtained during field testing and to hourly data from the weather station at the Columbus Metropolitan Airport (WBAN: 93842) [gathered from the National Centers for Environmental Information (NCEI, 2017b)].

2.2.5 Field Test – During February 2017 (winter, leaf-free period), particulate concentrations were measured in one-hour sampling sessions at 15 study sites (Figure 14), on rain free days, along major Columbus roads (Interstate 185, Highway 80, Highway 27, and

Highway 280), near busy shopping centers, and close to restaurants that produce smoke (e.g. Burger King). The roads that run along the study sites are considered principle arterial highways and experience average daily traffic ranging from 27,000 vehicles (Manchester Parkway) to 66,000 vehicles (Highway 80). As access to power was limited, the devices were operated for one hour to avoid exceeding the two-hour battery lifespan.

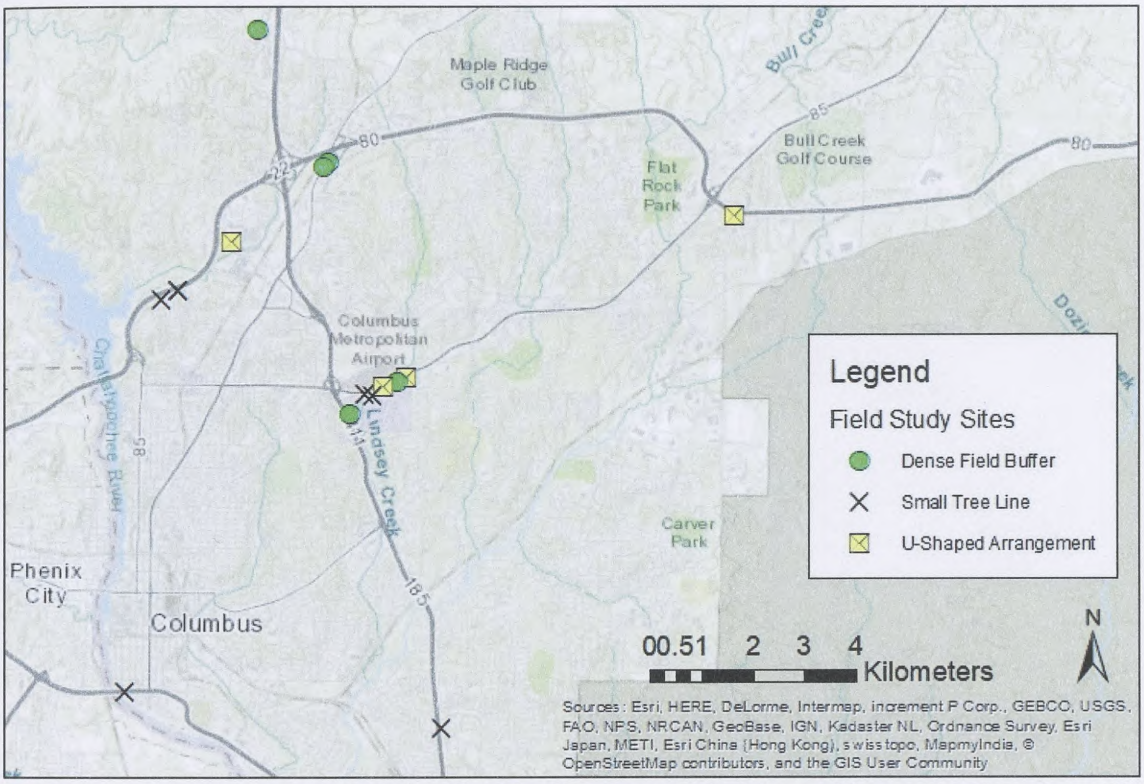


Figure 14. Field study sites with dense field buffer (green circle), small tree line (an x), and U-shaped arrangements (yellow square with x) indicated across Columbus, Georgia.

Sites were categorized as dense tree buffers (n = 5), small tree lines (n = 6), and U-shaped tree arrangements (n = 4). At eleven sites more than one location was tested so each tree arrangement type had 10 sample locations. Barriers, like fences, walls, and steep drop-offs in elevation, limited ability for more than one sample location at four sites. For each sample location two AirBeam units monitored particulate concentrations, one within the tree stand and one in the adjacent open area (Figure 10). In total, 60 sample locations (30 pairs of tree stand and open areas) were monitored.

The study sites were chosen based on proximity to major roads and busy shopping centers. The closeness to smoke producing restaurants was not accounted for in the original experimental design, and sites were not picked with this feature in mind. Each site needed a tree buffer with neighboring open area and a higher density of conifers than deciduous trees (as testing occurred during winter months). Sample locations picked within sites were based on distance from source, with first locations close to the road and successive locations set farther back as spaced allowed. Detailed pictures of each study site with marked test locations can be found in Appendix B. It should be noted that sites were not tested randomly as wind direction needed to correspond to the direction of particulate matter source and access to some sites (Haverty's, Lazyboy, Colony Bank, and the three churches) was limited to specific days and times.

At each site AirBeams were set at the height of 1.7 m, the average adult height in the U.S. (Ogden, Fryar, Carroll, & Flegal, 2004). All three units were started at the same location close to the street, in the open area, and collected data for at least five minutes. While positioned facing the direction of the road, a compass was used to determine the unit orientation, and units remained facing this direction for the entirety of each testing session. The two units with the most similar peak and average data were identified and used for subsequent testing. The two selected units were placed within the tree buffer and adjacent open area at the same distance from the road. The units sampled for five to ten minutes at this location. Units within the tree buffer and adjacent open area were moved back farther (if space allowed) for an additional five to ten minutes. All units were moved back to the start location for the final five minutes. At each location in the open area, the Kestrel 4000 was held at approximately 1.5 m and

temperature was allowed to equilibrate before wind speed, relative humidity, and temperature data were recorded.

Aakash et al. (2017) recommends frequent recalibrations in an environment similar to study conditions when using low-cost portable devices. Therefore, the five-minute start and end $PM_{2.5}$ data were used to correct for AirBeam discrepancies. The units' median values for the start/end period were calculated. A median ratio (unit 1: unit 3 and unit 2: unit 3) was then applied to the $PM_{2.5}$ data recorded at each location. Unit 3 was used as the standard for comparison testing as unit 3 was used at 27 of the sampling locations for tree/open concentration monitoring. (This matches the equivalency test results as unit 3 was found to vary between unit 1 and unit 2). For the three locations in which unit 3 was not deployed, a median ratio of unit 1: unit 2 was used to correct baseline differences. While a high correlation was found during equivalency tests among the units, this added corrective measure was used to ensure the data of importance, the tree and open $PM_{2.5}$ concentration data, aligned before final analysis. At three sites (the first site for each tree arrangement type), the units were corrected based on median ratio data for all sites and equivalency tests because the median ratio correction method (described above) was not employed until after testing was completed at these sites.

Columbus hourly weather from the weather station at the Columbus Metropolitan Airport (WBAN: 93842) airport for February 2017 were obtained from the National Centers for Environmental Information (NCEI, 2017b). Columbus hourly $PM_{2.5}$ concentrations for February 2017 were certified and obtained from the Georgia Environmental Protection Department - Air Branch Division. These data were used to assess if a relationship existed at city level between weather conditions and particulates. The daily averages were calculated and correlations examined between wind direction, wind speed, temperature, relative humidity, precipitation, and

Columbus $PM_{2.5}$ concentrations. Fort Benning controlled burn (Fort Benning's Smoke and Sound Archive, 2017) and regional agricultural fire (NESDIS, 2017) dates were gathered to determine if regional smoke impacted $PM_{2.5}$ and study sample locations' $PM_{2.5}$ concentrations.

The Columbus hourly $PM_{2.5}$ concentration were also used to assess whether study sample locations' $PM_{2.5}$ levels were influenced by localized sources. Each location's peak $PM_{2.5}$ values less the city $PM_{2.5}$ data were calculated. The results ranged from 2.0 to 92.6 $\mu g\text{-}m^{-3}$. Values 70 to 499 $\mu g\text{-}m^{-3}$ were labelled as high, 30 to 69 $\mu g\text{-}m^{-3}$ as medium, and below 29 $\mu g\text{-}m^{-3}$ as low sources. As a part of their Village Green Project, the EPA developed this scale for short-term air sensors in order to understand personal exposure to nearby air pollutants (Keating et al., 2016). This method matched what was experienced at the sites as the three high PM source locations were near local restaurants producing smoke and the one medium location occurred near a stop light with idling vehicles. These PM source level results were considered a random factor in the analysis as this was controlled for in the experimental design. The mean $PM_{2.5}$ for each location (tree vs open) and by type (dense, small, U-shaped) was used in an analysis of covariance (ANCOVA) with temperature, relative humidity, the wind direction versus the AirBeam unit orientation, and wind speed as covariates. IBM SPSS Statistics (Version 25.0) computer software was used for the statistical calculations (IBM Corp., 2017).

2.3 Results

2.3.1 AirBeam Equivalency Tests – Two of the three AirBeams had good correlation (Unit 1: $r = 0.78$, $p = 0.066$; Unit 2: $r = 0.85$, $p = 0.032$; Unit 3 $r = 0.85$, $p = 0.03$) to the state TEOM when $PM_{2.5}$ concentrations ranged from 0 to 10 $\mu g\text{-}m^{-3}$. The among unit equivalency tests yielded a total of 774 minutes (601 min for indoor test one, 85 min for indoor test two, and 88 minutes for the outdoor test) of $PM_{2.5}$ data for each AirBeam. All three units showed a

significant positive relationship to each other (Figure 15; Model II Regression Units 1 & 2: $F_{1,773} = 67471$, $r^2 = 0.989$, $p < 0.001$; Units 1 & 3: $F_{1,773} = 37019$, $r^2 = 0.980$, $p < 0.001$; Units 2 & 3: $F_{1,773} = 53262$, $r^2 = 0.986$, $p < 0.001$). All three units were not statistically different from each other when comparing the mean $PM_{2.5}$ among all three equivalency tests (ANOVA $F_{2,278} = 0.440$, $p = 0.645$). Overall, units 2 and 3 differed least as compared to unit 1 (Units 2 & 3 Tukey HSD $p = 0.991$; Units 1 & 2 Tukey HSD $p = 0.738$; Units 1 & 3 Tukey HSD $p = 0.661$; Table 6).

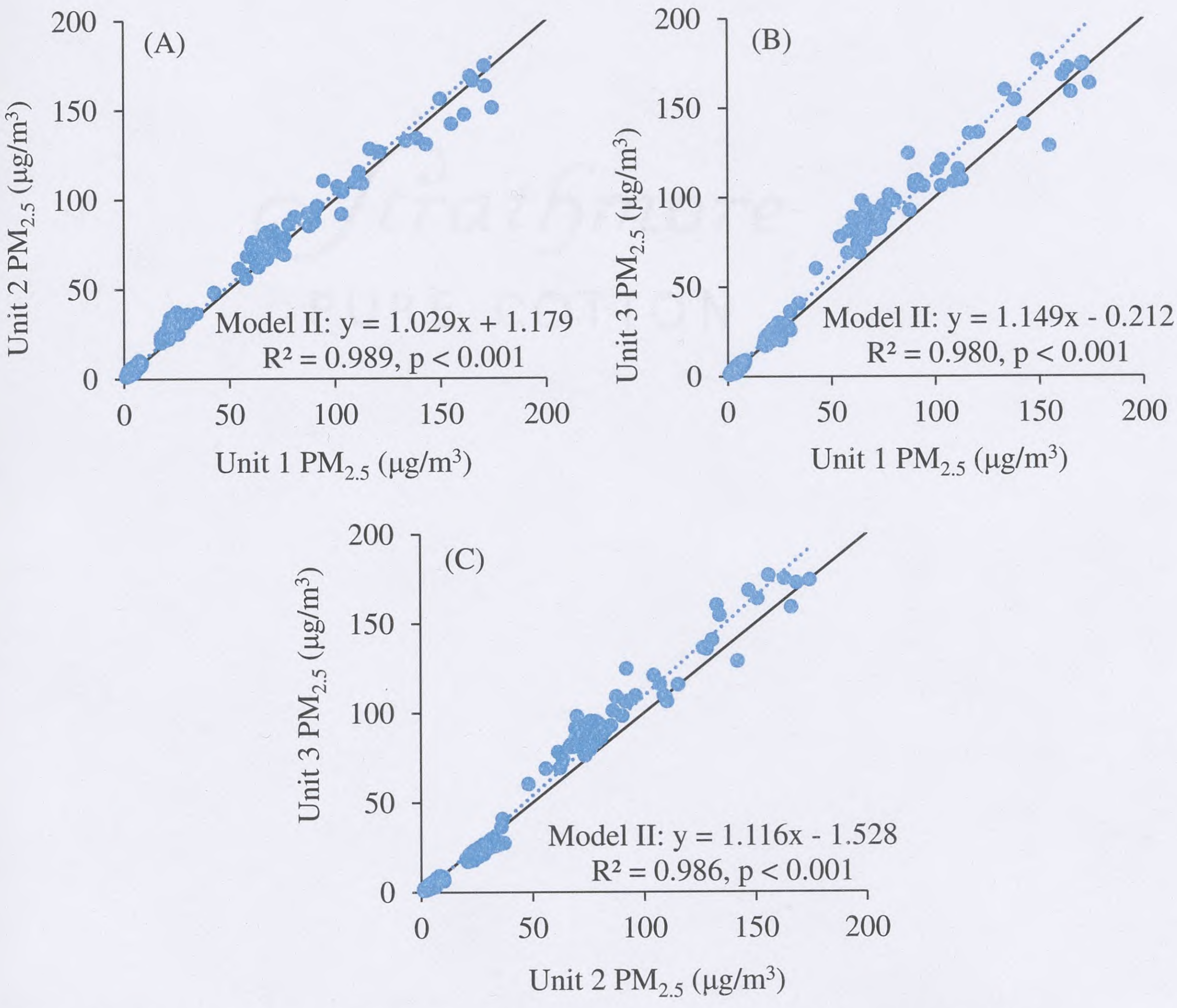


Figure 15. Airbeam $PM_{2.5}$ equivalency test results showing model II linear regression relationship between A) unit 1 v. unit 2, B) unit 1 v. unit 3, and C) unit 2 v. unit 3. 1:1 line denoted by solid line for reference.

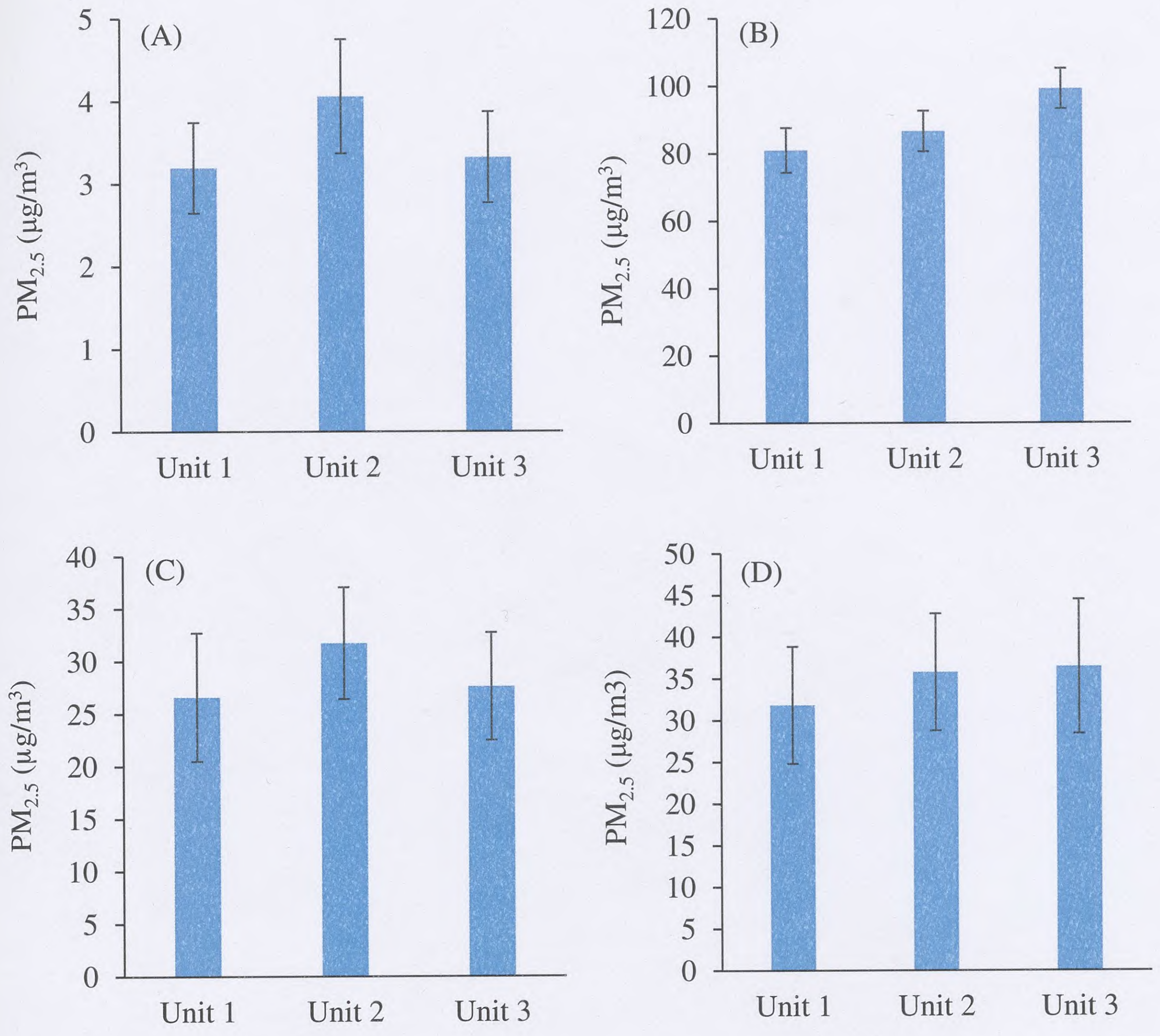


Figure 16. Equivalency test results $PM_{2.5}$ mean and 95% CI: A) indoor test one, D) indoor test two, C) outdoor test, and D) all tests combined.

To better understand the relationship among the units, comparisons were made among the three separate equivalency test results to determine how the units performed with various particulate concentrations and indoors versus outdoors (Table 6). The three tests varied in $PM_{2.5}$ concentration ranges: indoor test one ranged from 1 to 10 $\mu g\text{-}m^{-3}$, indoor test two ranged from 30 to 177 $\mu g\text{-}m^{-3}$, and the outdoor test ranged from 17 to 155 $\mu g\text{-}m^{-3}$. No statistically significant difference was found between the average $PM_{2.5}$ estimates for the three units for the first indoor

test (ANOVA $F_{2,81} = 2.322$, $p = 0.105$), the second indoor test (ANOVA $F_{2,62} = 2.562$, $p = 0.086$), and the outdoor test (ANOVA $F_{2,131} = 0.927$, $p = 0.398$). Units 1 and 3 varied less at lower concentrations (4 percent difference) versus higher concentrations (20 percent difference). The pairwise relationship results were similar between the first indoor test and the outdoor test. Units 1 and 3 have a 4 percent mean difference for the outdoor test (Figure 16).

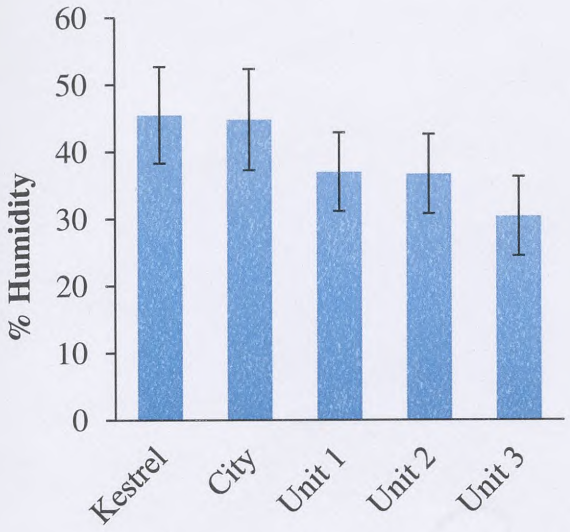
Table 6. Equivalency test results for AirBeams' $PM_{2.5}$ mean, 95% CI, and Tukey HSD p-values indicating no significant difference between $PM_{2.5}$ concentration means of the three units.

	Indoor Test 1 (n = 28)			Indoor Test 2 (n = 21)			Outdoor Test (n = 44)			Combined (n = 93)		
Units	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
Mean ±95%CI	3.2 ±0.5	4.1 ±0.7	3.3 ±0.6	80.9 ±12.1	86.5 ±10.6	99.1 ±11.4	26.5 ±6.1	31.7 ±5.3	27.6 ±5.1	31.8 ±7.0	35.8 ±7.0	36.4 ±8.0
Unit 1		0.120	0.955		0.777	0.078		0.407	0.966		0.738	0.661
Unit 2			0.209			0.284			0.557			0.991

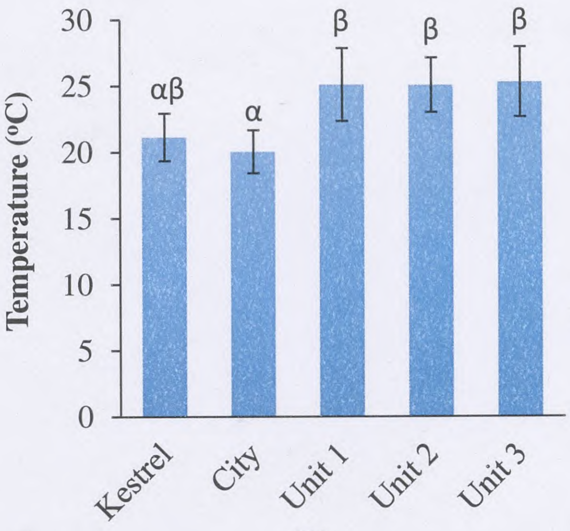
2.3.2 AirBeam Temperature and Relative Humidity – For average relative humidity, all three AirBeam units, the Kestrel and the City data were not significantly different (ANOVA $F_{4,89} = 2.425$, $p = 0.054$; Table 7). The mean relative humidity for unit 3 was significantly different (at an $\alpha = 0.1$ threshold) because it was 15 percentage points lower than Kestrel and City data and 7 percentage points lower than units 1 and 2. For temperature, a statistically significance difference was found (ANOVA $F_{4,89} = 2.425$, $p = 0.001$). Units 1, 2, and 3 showed mean temperatures that were 4 °C and 5 °C higher than the Kestrel and City, respectively (Figure 17).

Table 7. Relative humidity and temperature results: Kestrel, City, and AirBeams' mean, 95% CI, and Tukey HSD p-values.

	Relative Humidity (%)					Temperature (°C)				
	Kestrel	*City*	*Unit 1*	*Unit 2*	*Unit 3*	*Kestrel*	*City*	*Unit 1*	*Unit 2*	*Unit 3*
Mean ±95%CI	45 ±8.6	45 ±9.0	37 ±7.0	37 ±7.1	30 ±7.0	21 ±1.8	20 ±1.6	25 ±2.8	25 ±2.1	25 ±2.6
Kestrel		1.000	0.553	0.531	0.074		0.951	0.090	0.102	0.080
City			0.631	0.609	0.098			0.013	0.016	0.012
Unit 1				1.000	0.785				1.000	1.000
Unit 2					0.821					1.000



(A)



(B)

Figure 17. Hourly mean and 95% CI of A) relative humidity and B) temperature for Kestrel, City, and the three AirBeam units.

2.3.3 Field Test – The temperature obtained using the Kestrel 4000 during the field testing period ranged from 12.1 to 28.6 °C with mean of 21.2 °C, the relative humidity varied from 19.4 to 87.1 percent with mean of 51.1 percent, and the wind direction was variable at speeds of 0 to 5.1 m/s with a mean of 1.6 m/s. The temperature, relative humidity, wind direction in relation to unit orientation, and wind speed were assessed using linear regression and found to account for little variation in $PM_{2.5}$ across all locations ($r^2 = 0.110$, $F_{4,23} = 0.712$, $p = 0.592$). Therefore, the Kestrel obtained weather data were not included in the rest of the analysis.

The $PM_{2.5}$ concentrations differed across PM source level ($F_{2,52} = 41.635$, $p < 0.001$). The tree stand arrangements also differed significantly (ANCOVA $F_{2,52} = 3.939$, $p = 0.026$). No difference in $PM_{2.5}$ was found in open areas versus trees (0.9 percent difference) across all sites (ANCOVA $F_{1,52} = 0.003$, $p = 0.956$). Dense tree buffers differed as compared to small tree lines (43 percent difference; Tukey HSD $p = 0.001$) and U-shaped arrangements (31 percent

difference, Tukey HSD p = 0.018). However, small tree lines and U-shaped arrangements showed no differences in mean $PM_{2.5}$ (Tukey HSD p = 0.633). Dense tree buffers had higher $PM_{2.5}$ concentrations in trees versus open areas with a mean difference of 1.6 $\mu g\text{-}m^{-3}$. In contrast, small tree lines (mean difference of 0.1 $\mu g\text{-}m^{-3}$) and U-shaped (mean difference of 1.7 $\mu g\text{-}m^{-3}$) arrangements had higher $PM_{2.5}$ concentrations in open areas versus trees (Figure 18). This interaction was not statistically significant ($F_{2,52} = 0.716$, p = 0.493). Sample location details used in the analysis, including $PM_{2.5}$ corrected data and weather data, are located in Appendix B, Table 7.

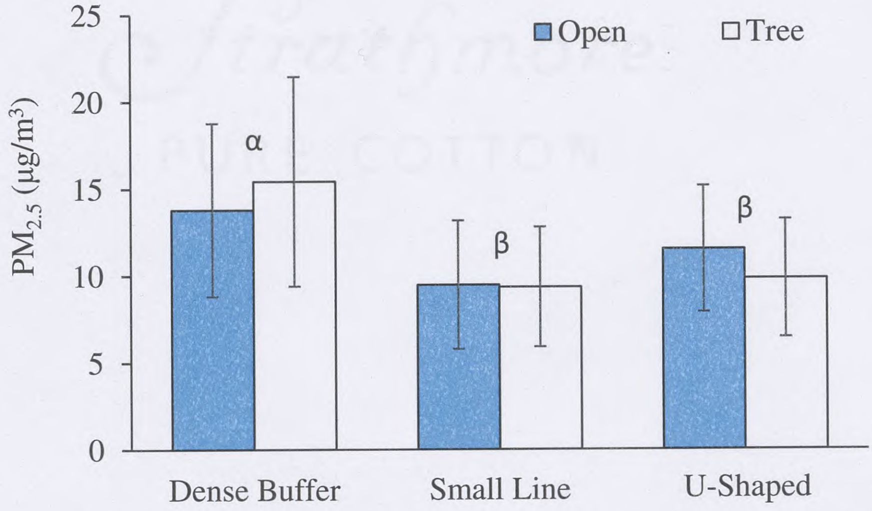


Figure 18. Comparison of the open and tree $PM_{2.5}$ concentrations mean and 95% CI within dense tree, small tree line, and U-shaped tree stands.

The Columbus city weather and $PM_{2.5}$ data for February 2017 were also analyzed to better understand the city's particulates in relation to atmospheric conditions. During February 2017, the city experienced 20 days with particulate concentrations less than 12 $\mu g\text{-}m^{-3}$, 7.4 days with 12.1 – 35.4 $\mu g\text{-}m^{-3}$, 12 hours with 35.5 – 55.4 $\mu g\text{-}m^{-3}$, and 2 hours with 55.5 – 150.4 $\mu g\text{-}m^{-3}$. All 24-hour averages were below 12 $\mu g\text{-}m^{-3}$, except for 5 days (February 5, 6, 11, 14, and 18), where concentrations were between 12.1 – 35.4 $\mu g\text{-}m^{-3}$, with the highest being 27.3 $\mu g\text{-}m^{-3}$ on February 18th.

Winds from the south or east bring fine particulate concentrations to the city during Fort Benning controlled burns. Fort Benning conducted controlled burns on February 1st, 11th, 17th, 24th, and 25th when winds were predicted to be from the north and west (Fort Benning's Smoke and Sound Archive, 2017). Overnight between February 17th and 18th the wind direction shifted, and winds from the southeast brought smoke into the Columbus area. This phenomenon was observed through an increase in $PM_{2.5}$ concentrations and the highest concentrations all month. Rain occurred later on the day of the 18th and reduced airborne particulates. An increase in $PM_{2.5}$ concentrations on February 11th could also be linked to Fort Benning prescribed burns. The remaining three 24-hour periods (February 5, 6, and 14) were most likely due to agricultural burning in other parts of the state (NESDIS, 2017). No field test days overlapped agricultural burning dates, and three test days took place on the same day as controlled burns (February 1st, 17th, and 24th). The city hourly $PM_{2.5}$ ranged from 0.7 to 11.9 $\mu g\text{-}m^{-3}$ with a mean of 5.7 $\mu g\text{-}m^{-3}$ during the hours when field testing occurred. Regional agriculture and Fort Benning fires were not found to contribute to field test particulate levels.

When Fort Benning prescribed burn data were removed, statistically significant correlations were found between city hourly $PM_{2.5}$ concentrations and the following city weather variables: wind speed ($r = -0.253$, $p < 0.001$), relative humidity ($r = -0.080$, $P = 0.043$), temperature ($r = 0.134$, $p = 0.001$), and precipitation ($r = -0.093$, $p = 0.018$). When daily averages for the month of February 2017 were calculated, the city $PM_{2.5}$ correlated positively with temperature ($r = 0.460$, $p = 0.024$) and negatively with relative humidity ($r = -0.433$, $p = 0.035$). No correlation was found with daily city $PM_{2.5}$ and wind speed ($r = 0.166$, $p = 0.438$). These findings suggest the daily changes in Columbus city $PM_{2.5}$ concentrations could be attributed to daily temperature and relative humidity fluctuations (Figure 19).

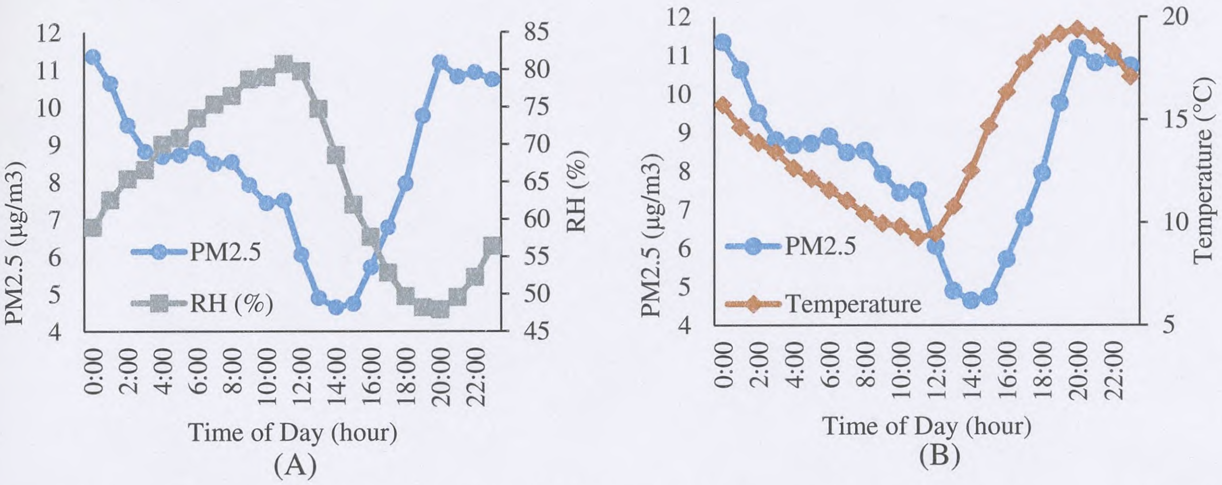


Figure 19. Average hourly data variability in Columbus February 2017 $PM_{2.5}$ as compared to A) relative humidity (RH) and B) temperature.

2.4 Discussion

2.4.1 AirBeam Performance - The stability, reproducibility, and reliability are concerns when using low-cost PM sensors (Rai et al., 2017). The three AirBeam units were assessed for these three factors during the equivalency evaluations and throughout the field study. Stability refers to the performance of the sensors remaining constant over a period of several months (Rai et al., 2017). The stability of the units was determined based on the change in unit median ratio between units over the course of the research. The median ratio for all tests for unit 1: unit 3 was 1.17 and for unit 2: unit 3 was 0.93. At the beginning of the equivalency testing period (October 2016), the median ratios were 1.01 (unit 1:3) and 0.92 (unit 2:3). At the start of the field testing median ratios were 1.03 and 0.91 (February 2017), and at the end of the field study they were 1.22 and 0.85, respectively. The change in the median ratio may be due in part to units not being cleaned during the testing period. The makers of the particle sensor inside the AirBeam suggest a lifespan of two to three years for the sensor if it is cleaned properly (Shinyei Technology Co., Ltd.). Jiao et al. (2016) found a change in response with "days of use" for the AirBeams they tested over 168 days. Given the small change in median ratio from beginning to end, the

AirBeams were found to be stable for the short time period of use. Longer testing sessions could prove problematic if particles collect on sensors over time.

Reproducibility is the difference in measurements found between similar devices (Rai et al., 2017). As $PM_{2.5}$ concentrations increased, the differences among the three units also increased. While at lower levels all three units did not differ greatly, and units 1 and 3 corresponded most closely. Units 1 and 2 correlated best at higher levels. Correlations among the units were the same in the field study as with equivalency tests. Particulate levels were low at many study sites with average concentrations of $12\mu g/m^3$ for all locations. Units 1 and 3 were found to be closer in mean and peaks, and, therefore, were used in tandem at half the study locations. As seen in the equivalency tests, the three units had the same response to stimuli and were found to have high reproducibility. These findings match the two studies previously conducted in regards to the high correlation found between AirBeam units (Jiao et al., 2016; Mukherjee et al., 2017).

The relative humidity and temperature sensors within each unit were used as an additional means to determine sensor reliability. The relative humidity and temperature sensors housed within the units were used as a gauge to ensure the units would not shut off, as AirBeams are programed to shut off at 100 percent relative humidity (Heimbinder and Besser 2014) and do not operate outside the temperature range of 0 to 45 $^{\circ}$C (Shinyei Technology Co., Ltd). The AirBeams' internal temperature and relative humidity were determined to not interfere with unit performance in the present study. The maximum relative humidity reading of all three units was 80 percent recorded on unit 2. The maximum temperature reading was 38 $^{\circ}$C and the minimum reading was 12 $^{\circ}$C, both measured on unit 1. The comparison between the AirBeams, Kestrel, and City weather data suggest that these sensors should not be used when collecting local

weather data. For example, all three units' mean temperatures were 17 percent higher than Kestrel and 22 percent higher than City mean temperatures. The AirBeams' black casing may account for the higher average temperatures seen in each unit as compared with the Kestrel and City data. Using the units during the summer in Columbus, Georgia, could prove problematic as temperatures average 33 °C in July and August (NCEI, 2017a) leading to a greater probability of exceeding the acceptable AirBeam internal temperature range.

The utility of the AirBeam $PM_{2.5}$ sensors for extended deployments and over multiple seasons with varying temperatures has yet to be established. One additional problem is the need to tether the device to a cell phone with a data plan to record data in the field. However, the AirBeams' high correlations, short-term stability, and reliability make these units legitimate sensors for the field studies. These units have limitations in data accuracy and usable temperature ranges, but the practicality of these devices is in their portability and ease of use. Field assistants were trained in less than five minutes to use the units and the accompanying cell phone app. The only complication occurred when field assistants did not save data properly. These features were found to be valuable when conducting the field study tests at multiple locations.

2.4.2 Fine Particulate Matter and Trees – The relationship between $PM_{2.5}$ and trees was statistically insignificant for all tree versus open sample pairs. While not significant, isolating by tree design found results similar to other studies. In this study, small tree lines had no impact on particulate levels as compared to surrounding open areas. This finding parallels the results of Hagler et al. (2012) that roadside buffers less than 10 m did not hinder particle transport beyond the vegetative barrier. Tong et al. (2015), Whitlow (2013), Liu et al. (2015) and Chen et al. (2015) found $PM_{2.5}$ concentrations were higher in dense tree buffers versus neighboring open

areas. While this study found no significance between all open versus dense tree buffer sample sites, it did find higher $PM_{2.5}$ concentrations in dense field sample locations as compared with other tree configurations. Overall the small difference between open and tree concentrations when using active monitors is consistent with the observations of Setälä et al. (2013).

For dense tree arrangements, the trees trap nearby $PM_{2.5}$ keeping particulates from leaving these tree barriers after being intercepted by the trees. Three locations used in this study did not have this relationship dynamic. For the Havertys and Lazyboy sites, $PM_{2.5}$ was essentially the same in the trees (m = 6.6 μg-m^{-3}) and the open (m = 6.9 μg-m^{-3}). These locations were tested in the same sampling session because these sites are located near the same high traffic shopping center. The notable differences versus the other seven locations was the lower than anticipated traffic volumes, 3°C higher temperature, and $PM_{2.5}$ that was 12 μg-m^{-3} lower than the other dense field locations. It is not possible to determine whether the higher open $PM_{2.5}$ concentrations is a confounding variable of these three locations, that, when removed, would make the overall dense tree buffer configuration results significant. Four of the dense field sites had a second location at farther distance from PM source. At each of these sites, a decrease in particulate concentration was measured with distance from PM source in both open and tree locations.

One dense tree location, the Manchester bike park, had the highest overall particulate matter concentrations of the entire study (tree m = 39.8 μg-m^{-3} and open m = 34.1 μg-m^{-3}). This location is located near a traffic stop, and cars and trucks were idling at the stop light with wind direction coming from the direction of this source during the sampling session. An increase in $PM_{2.5}$ is expected with idling vehicles, especially diesel trucks (Girard, 2014; Reff et al., 2009). The city $PM_{2.5}$ was 8.5 μg-m^{-3} during the test. Two other testing sessions (not used in statistical

analysis due to partial loss of data) at this location, saw the same relationship of higher particulates in the trees versus open areas at lower $PM_{2.5}$ levels (5.8 and 5.4 μg-m^{-3}). The sessions with data loss were conducted at low traffic periods, so this may account for the difference in particulate levels among sessions.

Another dense tree site located on Williams Road near the I-185 exit 12 on/off ramp had relatively elevated particulate levels (average of tree m = 17.0 μg-m^{-3} and open m = 15.3 μg-m^{-3}). This site (Figure 10A) offered the perfect dense field set-up with dense trees to the east of a cleared open area and across the street from two gas stations. The slightly elevated $PM_{2.5}$ in the area was thought to be due to proximity to these gas stations and idling traffic. The winds were calm for the majority of the testing session with the exception of the start. The lower winds could also lead to a build-up of pollution in the area (Tai et al., 2010).

The small tree line arrangement overall saw no statistical difference in tree $PM_{2.5}$ concentrations versus open $PM_{2.5}$ concentrations. The smaller number of trees in these arrangements are not able to noticeably reduce the fine particulate matter in the air. One site (the CSU softball field site) experienced high PM source levels, and open $PM_{2.5}$ concentrations were 2.9 μg-m^{-3} higher than tree concentrations. This may be a feature of this location. Tall pine trees populated the site. Wind direction aligned to bring smoke from a local Burger King to this site. Smoke from a meat cooking restaurant is higher in the air column, and the tree tops should intercept some of the particulate pollution. The parts of Columbus that have small tree line arrangements are shopping centers with meat cooking restaurants. As discussed in Chapter 1, often smaller ornamental trees frequent these areas as compared with the trees found at this site. The CSU softball site, with additional testing, could serve as a case study example of how tall

trees within small tree line designs can reduce fine particulate concentrations, which may influence the types of trees planted near restaurants that produce smoke.

While no relationship was found between field measured weather parameters and particulates, the city $PM_{2.5}$ and city temperature, relative humidity, and wind speed were found to have a significant correlation. This weather-particulate interaction at the city level could help explain some of the findings at sample locations. The direction of relationship found between city $PM_{2.5}$ concentrations and city temperature, relative humidity, and wind speed are consistent with Tai et al. (2010) findings for Southeastern U.S. and point to organic carbon (OC) and elemental carbon (EC) in the atmosphere. OC and EC are mainly caused by combustion of fossil fuels, which is consistent with Fort Benning controlled burns, vehicles, and smoke from restaurants as sources of particulates. Additionally, the daily decrease of particulates from morning to afternoon might explain the higher levels of particulate matter found at Cascade Hills Church (small tree line site) during the only sampling session that took place in the morning. All three locations sampled at the church averaged 12 $\mu g\text{-}m^{-3}$ the morning tested with relatively high traffic conditions (83 vehicles per minute), but two previous tests conducted in the afternoon measured particulate levels below 3 $\mu g\text{-}m^{-3}$ with higher traffic conditions (99 vehicles per minute).

The U-shaped tree arrangement also had no statistically significant difference between tree and open area particulate concentrations. At all PM source levels open area concentrations were higher by 1.7 $\mu g\text{-}m^{-3}$ when compared with tree concentrations. Not all study sites constituted ideal U-shaped tree stand arrangements, making city-wide generalizations difficult. However, the All Saints Presbyterian Church (Figure 10C) could be considered an almost perfect U-shaped tree stand with idling cars and diesel trucks at the opening of the U being the main

source of particle pollution. The average $PM_{2.5}$ at this site was low, but high winds (the highest recorded throughout the entire field study at 5.1 m/s) from the direction of the road brought an increase in particulate levels to the open area as compared to the trees. While sampling at the second location, the winds increased from 2.9 to 11 m/s. Unit 2 was left at the start/end location approximately 35 m from the road. Unit 1 was positioned 85 meters from the road in the open area, and unit 3 was the same distance in the tree line. With the increase in winds the particulate level also increased. This was seen with particulate levels peaking in series four times, first at unit 2 and 25 to 37 seconds later at unit 1. This dynamic of flowing through the opening of the U and not the trees highlights the impact the right wind direction and wind speed can have on particulate levels in this tree arrangement.

Two other U-shaped sites (Colony Bank and the corner of University Avenue and Manchester Expressway) were located across the street from restaurants that produced smoke during testing sessions. Wind direction was from the direction of these sources, and, consequently, these sites experienced high $PM_{2.5}$ concentrations. The Colony Bank site is also located near a shopping center parking lot. The U-shaped opening points towards this parking lot, while a small tree line exists directly opposite the restaurant. The Colony Bank site had the same average $PM_{2.5}$ levels (14.6 μg-m^{-3}) in the trees and open areas with a slightly elevated level in the trees (22.1 μg-m^{-3}) as compared to the open (21.9 μg-m^{-3}) when smoke was present. Conversely, at the corner of University Avenue and Manchester Expressway the U opens towards the restaurant. The average particulate concentrations were higher in the trees (12.9 μg-m^{-3}) versus the open (8.1 μg-m^{-3}) being 8.5 μg-m^{-3} higher in the trees over the open area when smoke was present. A bike path runs through the U-shaped opening at this site, meaning higher particulate levels are experienced by people using this path for recreation when the restaurant is

cooking meat. The difference between the two sites demonstrates how the right (or wrong) alignment of trees to PM source impacts particulate levels. The city of Columbus has several of these U-shaped tree designs because often only trees necessary for development are cleared in order to save tree canopy. This tree arrangement becomes problematic when it is located in areas where people frequent, like parks, and a PM source is near.

Every site, even those closely located (i.e. Manchester bike park and the corner of University Avenue and Manchester Expressway), has different localized PM sources that contribute to particulate levels. As discussed in methods and results sections, these localized sources must be controlled for in order to compare tree stands across the city. It is important to note these PM sources beyond controlling for background though. A study conducted in southeastern United States cities found wood combustion made up 25 to 66 percent, diesel exhaust 14 to 30 percent, meat cooking operations 5 to 12 percent, and vehicle exhaust 0 to 10 percent of the OC $PM_{2.5}$ concentrations (Zheng et al., 2002). The portion of fine particulate matter caused by vehicles in Atlanta, Georgia, has decreased due to vehicular emission regulations (Vijayaraghavan et al., 2012). The low wind speeds in Columbus cause vehicle particulate pollution to remain in the vicinity of the roads. This concept could be seen with low particulate levels at most locations near areas of high traffic (sample locations were greater than 15 m from the road), except those mentioned already as being located near smoke producing restaurants or heavy idling traffic with diesel trucks and cars.

Smoke producing restaurants were the sources of high PM in this study. Smoke from restaurants were found to pass through sampling areas within minutes. These higher concentrations plumes (73 to 93 $\mu g\text{-}m^{-3}$) can impact people in sensitive groups such as those with respiratory issues (EPA, 2016b). A study conducted in Los Angeles found meat cooking

establishments contribute 21 percent of the OC $PM_{2.5}$ concentrations in the city (Rogge, Hildemann, Mazurek, Cass, & Simoneit, 1991). Reducing pollution at the source is the best way to combat it, but cities have shown little will to regulate restaurant emissions (Murphy, 2015; Chaudhury, 2015). Taller trees can assist in blocking the spread of smoke from these point sources, as seen at the Colony Bank and CSU softball field sites. Future studies should focus on this dynamic looking at height of trees near smoke producing restaurants as well as distance to source.

This field study test had limitations. The testing took place for one month, only encompassing one season of the year. The study, while city wide, was on a small scale based on the number of locations visited. The small sample size limits the ability to apply findings beyond specific sites tested. The use of the Kestrel 4000 and its limitations may be the main reason for the insignificant statistical relationships seen between $PM_{2.5}$ and weather conditions measured at each site. The Kestrel 4000 is not capable of determining wind direction. Wind speed and direction were variable and Kestrel sampling was not continuous, rather a sample point method was employed. Continuous weather monitoring with similar sample resolution as the AirBeam is needed to assess if localized weather influenced $PM_{2.5}$ concentrations.

The time of year offers some complications as deciduous trees had shed their leaves before this study took place. Leaf absorption of ultrafine particulates is limited (Hemond & Fechner, 2014). Fine and ultrafine particulates settle on leaves through deposition. $PM_{2.5}$ levels on leaves are lower than PM_{10} due to gravitation deposition properties (Beckett et al., 2000; Freer-Smith, 2005; Sæbø et al., 2012). Conifers are better at capturing particulate matter due to leaves having a waxy coating, (Sæbø et al., 2012), high leaf area index, and no annual loss (Yang et al., 2015). Broadleaf trees have the second greatest capacity to capture airborne particles

(Beckett et al., 2000; Yang et al., 2015). All study sites had conifers trees (site pictures in Appendix B show sites during leaf-off season). Focusing on locations that had more conifer tree species during the winter makes findings specific to study locations during the one season. A Beijing study comparing forest $PM_{2.5}$ concentrations to open area concentrations found the same higher concentrations in forests during leaf-off periods (Liu et al., 2015), while Cai et al. (2017) found higher deposition levels in urban settings in winter months. The composition and main sources of fine particulate matter can change throughout the year, with more wood combustion in the winter and higher biogenic VOC in the summer (Tai et al., 2010; Malm, Schichtel, Pitchford, Ashbaugh, & Eldred, 2004). These changes could have an impact on tree-particulate interactions throughout the year in addition to leaf-on vs leaf-off differences (Cai et al., 2017).

Additional field study tests need to be conducted to determine the appropriate level of tree services in reducing $PM_{2.5}$ taking into account various localized particulate sources. The insignificant statistical findings between open and tree $PM_{2.5}$ concentrations point to the low ability of conifer trees at these study locations to trap particulates during the winter season. A larger sample size, across multiple seasons will help in determining if similar findings are significant annually and city-wide for the city of Columbus. Dense tree barriers may reduce $PM_{2.5}$ concentrations in other seasons. Additionally, taller trees may assist in the reduction of airborne smoke particulates from nearby restaurants. The results of this study highlight the need to focus on various tree configurations in relation and distance to different particulate sources when considering utilizing trees as a deterrent to particulate pollution. Low-cost, portable sensors, like the AirBeam, can aide in determining neighborhoods with higher relative $PM_{2.5}$ concentrations and identify sources, as well as, assist in determining appropriate tree design and placement to reduce pollution.

DISCUSSION

When looking at air quality benefits, the $PM_{2.5}$ results found using the i-Tree model in Chapter 1 should be discussed with respect to the results of the $PM_{2.5}$ field tests conducted in Chapter 2. The field tests (i.e. Chapter 2) can better characterize the interactions between trees and $PM_{2.5}$ on a site by site level and facilitate generalizations regarding if the PM removal associated monetary savings are valid for the Columbus area. The field study documented higher particulate levels in treed versus adjacent open areas in seven of the ten dense field sample locations tested. On average, the observed difference was not great (1.6 $\mu g\text{-}m^{-3}$). The greatest variation in $PM_{2.5}$ was measured at the Manchester bike park, the area with highest average particulate levels for the whole study.

Most of the northern portion of Columbus consists of dense fields of tree. Census tracts 103.02 (Bradley Park area, south of 102.01), 33.01 (area northwest of the I-185, highway 280 intersection), 105.02, and 105.01 (to the west of 108.02) are less developed with higher tree canopy percentages and dense tree buffers are the main type of tree arrangement (See Figure 8 or Appendix A, Figure 2 to locate tracts). Assuming the i-Tree Tool removal rates are accurate, these nine tracts contain 14,516 ha (35,871 acres) of canopy that could potentially remove 15 tons of particulates (or 18 percent of the original overall city removal of this pollutant) during Columbus winters (i-Tree Tool removal rate was adjusted to account for the field study being conducted during leaf-off period). The notion this removal rate is valid for these areas hinges not only on dense tree stands trapping particulates, but also on particulate pollution being the same in these nine tracts as it is for the whole city. This rate depends of pollution levels gathered at the Columbus Airport. Witlow (2009) argues localized particulate concentrations differ from those detected by regional monitors. These nine tract areas are less populated with less traffic

and meat cooking restaurants, and, therefore, the fine particulate levels may not be as high as those near the airport. Regional fires may contribute to particulate pollution in these mainly northern tracts with the right wind direction. However, based on the tested conducted during controlled burns at increasing distance from Fort Benning by Baumann (2005) and Liu (2010), the smoke from Fort Benning controlled burns will likely disperse before significantly impacting these areas.

The remaining 44 census tracts contain residential, business, and shopping neighborhoods with various tree arrangements. $PM_{2.5}$ removal by trees is not as accurate in these areas using the i-Tree Tool. Additionally, if the results from the field study hold, U-shaped tree stands have open areas with elevated particulate pollution, and small tree stands would not impact this pollution. Therefore, the areas of the city with the greatest population would not observe trees reducing particulate levels.

In addition to limitations previously discussed, the applicability of the field test results relative to the i-Tree $PM_{2.5}$ removal rates is questionable. The field study took place over the course of one month (February), while the i-Tree removal rates are annual rates. Simply adjusting the rate to cover one season, as above, does not account for the change in particulate levels, sources, and trees across all seasons. While Columbus, GA, experiences similar wind conditions throughout the year, other seasonal factors such as tree leaf off, weather, and fine particulate matter variations were not taken into account in this research. One big difference between summer and winter seasons is the existence of more leaves on trees to intercept particulates. Trees emit more volatile organic carbons during the summer, which increases ozone and can lead to eventual increase in particulates within and around trees (Yang et al.,

2015). These seasonal dynamics could change the interactions observed between trees and particulates in the field study.

Neither studies' results unequivocally conclude that trees abate $PM_{2.5}$ in Columbus. Additional research is needed to assess the effectiveness of trees for reducing particulates specifically as tree planting activities relate to particulate reduction. Researchers have argued that planting trees solely for the purposes of improved health from reduced particulates is in "vain", and that government funds should be used to reduce pollutants at their source (Whitlow et al., 2014). While this argument is valid, as discussed in Chapter 2, not all pollutant sources are regulated at the source. A telling example is the lack of desire to control pollutants from meat cooking restaurants (Murphy, 2015). Trees also help cities in other ways, like cooling air temperatures, reducing storm water runoff, and improving health not related to air quality (Pataki et al., 2011). Therefore, the aim of tree planting should be to provide maximum total benefits of the services offered by trees as a whole and not simply their ability to remove particulate pollution.

In this research, the ability of trees to reduce air pollutants was assessed using high spectral analysis that quantified tree canopy and its associated benefits. The overall the canopy for Columbus, Georgia, at 52 percent, meets the criterion set by the American Forests Urban Forest Program for ideal urban canopy cover (Leahy, 2017), but the variations in percent cover across the city leaves the impervious downtown, business, and shopping center areas lacking in good canopy cover. Urban canopy cover recommendations are made so cities can benefit from the ecosystem services trees provide, but simply adding canopy does not mean these benefits are fully utilized. Tree placement, tree type, and tree design need to be considered, and the latter often is not when considering urban vegetation plans.

The city's high tree canopy cover is estimated to remove 1,900 tons of criterion air pollutants and sequesters 282,000 tons of carbon dioxide annually. The high spectral imagery analysis highlighted large tree canopy and air quality benefit disparities over time across the city of Columbus. Areas of highest removal of gaseous air pollutants is dependent on location of trees. These are the northern sections of the city, which also have fewer air pollutant sources. Higher pollution and a lower number of trees in more urban areas of the city (downtown and shopping centers) lead to lower pollution removal.

This research utilized a low-cost, portable particulate sensor to analyze the interactions between fine particulate matter and tree stand designs. AirBeams are affordable ($250/unit) and easy to use. Accurate, more expensive equipment, is not feasible for studies of this scale and length or reasonable for citizen use. The three units tested in this study effectively measured $PM_{2.5}$ variations at multiple sample locations. The unestablished stability of the AirBeam over extended periods and its temperature restraints limits usability for longer testing periods. AirBeams and other portable sensors allow simple, city-wide field studies to be performed. Use of more affordable sensors leads to more measurements by more people, which in turn yields big data with incredible potential. Open access to big data allows for new possibilities in understanding the environment. The possibilities, given advancements in portable sensors, are wide, and can be very valuable in understanding air quality as it relates to many aspects of an urban setting at localized levels.

$PM_{2.5}$ has more complex interactions with trees than other air pollutants and removal is dependent on local PM sources, weather conditions, and tree design. Small tree lines have no discernable impact on $PM_{2.5}$ concentrations and dense tree buffers trap $PM_{2.5}$ resulting in slightly higher tree particulate concentrations as compared to open areas. U-shaped tree stand

interactions with particulates depended on location of the open area within the tree stand in relation to notable PM sources. Overall, in the winter, trees had little impact on particulate concentrations as compared with open areas. While the city of Columbus has, on average, low wind speeds, wind direction played a key role in particulates reaching sampling locations. Future tree plantings and removal should take note of areas with lower tree canopy as well as paying attention to tree arrangement and proximity to PM sources to better assist in the removal of air pollutants. Also, as the dense tree buffer arrangements trap pollution particles, the clearing of fields of trees should be seen as impeding the removal of $PM_{2.5}$ along with other air pollutants.

Given the limitations of the study conducted, future research is needed to better understand the relationship between tree stand arrangements and fine particulate matter involving more sample locations across multiple seasons. Research should also focus on alternative fine particulate sources in addition to that from vehicles, like restaurants that produce smoke. Using portable monitoring devices to assess smoke fallout and interception by placing sensors in trees of varying height would be useful in determining tree height effect on local pollution produced by restaurants. Research is lacking in this area, and more portable sensors allows for more methods to asses these interactions.

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APPENDICES

APPENDIX A – COLUMBUS TREE CANOPY ANALYSIS SUPPLEMENTAL DATA

Table 1. 2005 iso cluster values and reclassified values for 10 clipped sections.

	Section Names Used to Identify									
	Midland East	Midland Middle	Midland West	Smith_River	Smith	Middle_NW (Fortson)	Middle_NE (Fortson)	Middle_S (ColumbusS)	NCol_SW	SCol_SW
Iso Cluster Name:	isocluster25	isocluster23	isocluster27	isocluster59	isocluster63	isocluster73	isocluster75	isocluster71	isocluster79	isocluster81
Values	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value
1	2	2	2	1	2	1	1	1	1	1
2	2	2	1	1	2	1	1	1	1	1
3	1	1	1	2	2	1	1	1	1	1
4	1	1	1	2	1	1	1	1	2	1
5	1	1	2	2	1	1	1	1	2	1
6	2	1	1	2	1	1	1	1	2	1
7	1	1	1	2	1	1	1	1	2	1
8	1	1	1	2	1	1	1	1	2	2
9	1	1	1	2	1	1	2	1	2	2
10	1	1	1	2	1	1	1	2	2	2
11	1	1	2		1	1	1	1	2	2
12	1	1	1		1	1	1	1	2	2
13	1	1	1		1	2	2	2	2	2
14	1	1	1		1	1	2	2	2	2
15	1	2	1		1	1	1	2	2	2
16	1	1	1		1	2	2	2	2	2
17	1	1	2		1	2	1	2	2	2
18	1	1	1		2	2	2	2		
19	1	1	1		1	2	2	2		
20	1	2	2		1	2	2	2		
21	1	1	1		1	2	2	2		
22	2	1	1		1	2	2	2		
23	2	1	1		1	2	2	2		
24	2	1	2		1	2	2	2		
25	2	1	2		1	2	2	2		
26	2	1	1		1	2	2	2		
27	2	1	2		1	2	2	2		
28	2	1	2		1	2	2	2		
29	2	2	2		1	2	2	2		
30	2	1	2		2	2	2	2		
31	2	2	2		1	2	2	2		
32	2	2	2		1	2	2	2		
33	2	2	2		1	2	2	2		
34	2	2	2		2	2	2	2		
35	2	2	2		2	2	2	2		
36	2	2	2		2	2	2	2		
37	2	2	2		2	2	2	2		
38	2	2	2		2	2	2	2		
39	2	2	2		2	2	2	2		
40	2	2	2		2	2	2	2		

Table 2. 2010 iso cluster values and reclassified values for 20 clipped sections.

	Section Names Used to Identify																			
	smithnw	smithse	smithne	2frtnw	FortsonSW	frtne	frtse	colsw	colnw	colse	colne	midnw	midne	midsw	midse	ochne	upisw	upise	upinw	upise
Iso Cluster Name:	smnw1_iso20	smithse_iso40	smithne_iso40	2frtnw_iso40	fnwiso40401	frtne_iso40	frtse_iso40	colsw_iso40	colnw_iso40	colse_iso40	colne_iso40	midnw_iso40	midne_iso40	midsw_iso40	midse_iso40	ochne_iso40	upisw_iso40	upise_iso40	upinw_iso40	upise_iso20
Values	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value	New Value
1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3	2	2	2	1	2	2	2	2	2	2	2	2	1	1	2	1	1	2	2	
4	1	2	1	1	2	2	2	1	2	2	2	1	2	2	1	2	2	1	2	2
5	1	2	1	1	2	1	2	2	2	2	2	1	1	1	2	2	1	1	1	1
6	1	2	2	2	2	2	1	2	2	1	1	2	1	1	1	1	2	1	1	1
7	1	2	1	1	2	1	2	1	1	1	2	2	1	2	1	1	1	2	2	1
8	1	2	1	2	1	1	2	2	2	1	2	1	2	1	1	2	1	1	1	1
9	1	2	1	1	2	2	1	2	2	1	1	1	1	1	2	1	1	1	1	1
10	1	2	1	1	2	1	2	1	1	1	1	1	1	2	1	2	1	1	1	1
11	1	1	2	2	1	1	1	1	1	2	2	2	1	1	2	1	1	1	2	2
12	1	1	1	1	2	2	1	2	2	1	1	1	2	1	1	1	2	1	1	1
13	1	2	1	1	1	1	2	1	2	2	1	1	1	1	1	1	1	1	1	2
14	1	1	1	2	2	1	1	2	1	1	2	1	1	1	1	2	1	1	1	2
15	1	1	1	1	1	2	1	1	1	2	1	1	1	2	2	1	1	2	1	1
16	1	2	1	2	2	1	2	2	2	1	1	2	1	1	1	1	2	1	1	1
17	1	1	2	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	1	2
18	2	1	1	2	1	1	2	1	1	1	1	1	2	1	1	1	1	1	2	1
19	1	2	1	1	2	1	1	2	2	1	1	1	1	1	2	1	1	1	1	1
20		1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	2
21		1	1	1	2	2	2	1	2	2	1	1	1	1	1	1	1	2	1	
22		2	2	2	1	1	1	2	2	1	1	1	2	1	1	2	1	1	1	
23		1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	
24		2	1	1	2	1	1	1	2	1	1	1	1	2	1	2	1	2	1	
25		1	1	1	1	2	2	2	1	1	1	1	1	1	1	2	2	2	2	
26		1	1	2	2	1	1	1	2	2	2	1	1	2	1	2	1	1	1	
27		1	2	1	1	1	2	2	1	2	2	2	1	2	1	2	1	1	1	
28		1	1	1	1	1	2	2	2	2	1	1	2	1	1	2	1	1	2	
29		2	1	1	2	2	1	1	2	2	2	1	1	2	1	2	1	1	1	
30		1	1	1	2	1	2	1	2	2	2	2	1	2	2	2	1	2	2	
31		2	1	1	2	1	2	2	2	2	2	1	1	2	1	2	2	1	2	
32		1	2	2	2	2	2	2	2	2	2	1	1	2	2	2	1	1	1	
33		2	1	1	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	
34		1	1	2	2	1	2	2	2	2	2	1	1	2	1	2	1	2	1	
35		1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	
36		1	1	2	2	1	2	2	2	2	2	1	2	2	2	2	2	1	1	
37		1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	
38		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	
39		1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	
40		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	

Table 3. 2015 iso cluster values and reclassified values for 4 clipped sections.

	Section Names Used to Identify			
	Columbus	Midland, Upitoi, Ochillee	Fortson South	Smith-Fortson N
Iso Cluster Name:	columbus_40	midupi_40	fortsonS_40	smithfort_40
Values	New Value	New Value	New Value	New Value
1	2	2	2	2
2	2	2	2	2
3	2	2	2	2
4	1	2	1	2
5	1	2	1	2
6	1	2	1	2
7	1	1	2	2
8	1	1	1	2
9	1	1	1	2
10	1	1	1	1
11	1	1	1	1
12	1	1	1	1
13	1	1	1	1
14	1	1	1	1
15	2	1	1	1
16	2	1	2	1
17	2	1	1	1
18	2	1	2	1
19	2	1	2	1
20	2	1	2	1
21	2	1	2	1
22	2	1	2	1
23	2	1	2	1
24	2	1	2	1
25	2	2	2	1
26	2	2	2	1
27	2	2	2	1
28	2	2	2	2
29	2	2	2	1
30	2	2	2	2
31	2	2	2	2
32	2	2	2	2
33	2	2	2	2
34	2	2	2	2
35	2	2	2	2
36	2	2	2	2
37	2	2	2	2
38	2	2	2	2
39	2	2	2	2
40	2	2	2	2

Table 4. Reference point locations and values.

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y	FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y	FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
0	1	2	2	2	2	2	2	2119141.6	939936.367	41	1	2	2	1	2	1	1	2048263.36	910010.857	82	1	1	1	1	1	1	1	2070458.049	896970.8416
1	1	2	2	2	1	2	2	2053522.64	937371.086	42	1	2	2	2	1	1	1	2047380.73	941489.833	83	1	1	1	1	1	1	1	2017252.737	948159.3252
2	1	1	2	2	1	2	1	2059919.32	900392.757	43	1	2	2	2	2	2	2	2052470.1	909136.997	84	1	1	1	1	1	2	1	2076388.692	924362.8804
3	1	2	2	2	2	2	2	2078161.99	917319.254	44	1	1	1	1	1	1	1	2128229.88	928448.121	85	1	2	2	2	1	2	2	2057334.604	893746.9063
4	1	1	1	1	1	1	1	2083086.96	933045.195	45	1	1	1	1	1	1	1	2107872.96	935790.295	86	1	1	1	1	1	1	1	2059753.691	938138.3353
5	1	1	1	1	1	1	1	2037389.7	942211.915	46	1	2	2	2	2	2	2	2049363.32	919152.781	87	1	1	1	2	1	1	2	2050096.444	871217.5315
6	1	2	2	1	2	2	1	2041286.95	924647.189	47	1	1	2	1	1	2	1	2120685.28	932255.702	88	1	1	1	1	1	1	1	2094530.738	939530.786
7	1	2	2	2	2	2	2	2054239.11	897175.777	48	1	1	1	1	2	1	1	2079770.34	916397.279	89	1	2	2	2	2	2	2	2045176.692	898238.0519
8	1	2	2	2	2	2	2	2130102.13	931281.711	49	1	1	1	1	2	1	1	2086545.97	937958.824	90	1	1	1	1	1	1	1	2047999.264	940049.1376
9	1	2	2	2	2	2	2	2065370.95	893297.089	50	1	1	1	1	1	1	1	2031966.16	936421.73	91	1	1	1	1	1	1	1	2069690.851	915150.0115
10	1	2	2	2	2	2	2	2079001.04	923773.623	51	1	1	1	1	1	1	1	2089024.86	932381.832	92	1	1	1	1	1	1	1	2039246.375	936445.8179
11	1	2	1	1	2	1	1	2071317.48	936971.514	52	1	1	1	1	1	1	1	2067695.09	900757.577	93	1	1	1	1	1	1	1	2058200.236	879648.4822
12	1	2	2	2	2	2	2	2081398.9	921526.564	53	1	2	2	2	2	2	2	2059141.07	894497.231	94	1	2	2	2	2	2	2	2049084.809	912331.8854
13	1	2	2	2	2	2	2	2055469.57	877891.757	54	1	2	2	2	2	2	2	2051856.96	924070.657	95	1	2	2	2	2	2	2	2066562.133	916134.5882
14	1	2	2	2	2	2	2	2063657.98	925857.82	55	1	2	1	1	2	1	1	2092605.14	933969.726	96	1	1	1	1	1	1	1	2061884.035	901309.9351
15	1	1	2	1	1	2	1	2074038.39	934258.466	56	1	2	2	2	2	2	2	2077755.07	900847.536	97	1	1	1	1	1	1	1	2033445.349	945957.0863
16	1	1	1	1	1	2	1	2092142.93	939608.63	57	1	1	1	1	1	1	1	2068186.1	941935.764	98	1	1	1	1	1	1	1	2038228.34	943599.538
17	1	1	1	1	1	1	1	2061463.9	905258.805	58	1	2	2	2	2	1	2	2050991.21	872271.289	99	1	1	1	1	1	1	1	2086076.34	930502.8865
18	1	2	1	1	2	1	1	2039851.44	925154.529	59	1	2	2	2	1	2	2	2061581.28	893262.311	100	1	1	1	1	1	1	1	2124332.257	937138.6106
19	1	2	2	2	2	2	2	2092041.24	933547.152	60	1	2	2	2	2	2	2	2079803.33	911282.37	101	1	2	2	2	2	2	2	2053692.963	923416.7245
20	1	1	1	1	1	1	1	2084467.45	921848.04	61	1	1	1	1	1	1	1	2046682.6	897115.661	102	1	1	1	1	1	1	1	2051451.921	884167.6366
21	1	1	1	1	1	1	2	2029126.96	938120.4	62	1	2	2	2	2	2	2	2119212.5	928892.865	103	1	2	2	2	2	2	2	2075786.974	895005.1716
22	1	2	1	2	2	1	2	2061680.84	907856.271	63	1	1	1	1	1	1	1	2088475.32	919062.11	104	1	1	1	1	2	1	1	2039991.563	945369.0021
23	1	2	2	2	2	2	2	2062603.57	886784.876	64	1	1	1	1	1	1	1	2135219.3	924057.19	105	1	1	1	1	1	1	1	2032581.79	944820.2472
24	1	2	1	1	2	1	1	2040902.22	920913.003	65	1	2	2	2	2	2	2	2071694.73	927789.154	106	1	2	2	2	1	2	2	2041357.59	912521.4113
25	1	2	2	2	2	2	2	2056825.65	916799.818	66	1	1	1	1	2	1	1	2076213.21	933816.256	107	1	2	2	2	2	2	2	2035778.538	936680.5567
26	1	1	1	1	1	1	1	2070097.21	909935.266	67	1	1	1	2	1	2	2	2056099.68	941458.814	108	1	1	1	1	1	1	2	2040126.218	932263.647
27	1	2	2	2	2	2	2	2027485.33	930649.906	68	1	1	1	1	1	1	1	2113630.06	932755.223	109	1	1	1	1	1	2	1	2044831.624	927155.7255
28	1	2	2	2	2	2	2	2048622.04	895002.266	69	1	1	1	1	2	1	1	2036827.06	943697.498	110	1	1	1	1	1	1	1	2087642.826	940081.2689
29	1	1	1	1	1	1	1	2062103.99	897116.245	70	1	1	1	1	1	1	1	2032202.04	946325.896	111	1	1	2	1	1	2	1	2055767.79	899655.5946
30	1	2	2	2	2	2	2	2044920.75	921667.753	71	1	1	1	2	1	1	2	2066787.43	937649.223	112	1	2	2	2	2	2	2	2065819.006	884095.3669
31	1	2	2	2	2	2	2	2059334.03	930062.803	72	1	2	1	1	2	1	1	2124810.8	932539.34	113	1	2	2	2	2	2	2	2101338.313	937841.7308
32	1	1	1	1	1	1	1	2068991.02	896714.842	73	1	1	1	1	1	1	1	2049671.56	934193.781	114	1	2	2	2	2	2	2	2074718.172	919372.2812
33	1	1	1	1	1	1	1	2107118.59	931364.409	74	1	2	2	1	2	2	1	2041734.74	901126.217	115	1	2	2	2	2	2	2	2135256.778	927029.4986
34	1	1	1	1	1	1	1	2065703.45	947865.07	75	1	2	1	2	2	1	2	2060817.32	883679.716	116	1	2	2	2	2	2	2	2078537.545	915721.0637
35	1	2	2	2	2	2	2	2052929.76	876551.656	76	1	1	1	1	1	1	2	2114995.62	939140.707	117	1	2	2	2	2	2	2	2062814.069	899883.3902
36	1	2	2	2	2	2	2	2075367.34	901383.257	77	1	1	1	1	1	2	1	2074301.09	936793.023	118	1	1	1	1	1	1	1	2116206.745	934928.8279
37	1	2	2	2	1	2	1	2056067.12	946860.522	78	1	1	1	1	1	1	1	2100744.08	929805.436	119	1	2	2	2	2	2	2	2128083.3	935867.7719
38	1	1	1	1	1	1	1	2133744.42	931363.273	79	1	1	1	2	1	1	2	2027014.94	944716.249	120	1	1	2	2	1	2	2	2072731.526	893886.1758
39	1	1	1	1	1	1	1	2050609.99	886708.419	80	1	1	1	2	1	1	2	2122727.25	930355.815	121	1	2	2	2	1	2	1	2056559.26	923524.7929
40	1	1	1	1	1	1	1	2045504.05	927889.092	81	1	2	2	2	2	2	2	2049647.11	894396.525	122	1	2	2	1	2	2	1	2047278.567	945036.2017

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y	FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y	FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
123	1	1	1	1	1	1	1	2045500.35	910037.471	164	1	2	2	2	2	2	2	2050953.8	897859.125	205	1	2	2	2	2	2	2	2115961.663	936089.8275
124	1	2	2	2	2	2	2	2050702.99	871194.316	165	1	1	1	1	1	1	1	2118732.4	932517.121	206	1	2	2	2	2	2	2	2121247.168	939335.9445
125	1	2	2	2	2	2	2	2072781.92	896331.571	166	1	2	2	2	2	2	2	2045382.44	868155.06	207	1	1	1	1	1	2	1	2133842.228	925372.7866
126	1	2	1	1	2	1	1	2059413.54	946086.351	167	1	1	1	1	1	1	1	2132824.05	932492.431	208	1	2	2	2	2	2	2	2091435.736	925848.6008
127	1	2	2	2	2	2	2	2055389.97	888857.803	168	1	2	2	2	2	2	2	2059719.96	930953.979	209	1	1	1	2	1	1	2	2056942.198	895154.3632
128	1	1	1	1	1	2	1	2072305.49	886592.677	169	1	2	2	2	2	2	2	2027697.66	940888.831	210	1	1	1	1	1	1	1	2130030.025	924905.7655
129	1	1	1	1	2	1	2	2087844.18	937189.58	170	1	1	1	1	2	1	1	2051534.55	903477.004	211	1	2	2	2	2	2	1	2048167.155	878527.381
130	1	1	1	1	1	1	1	2058537.62	947167.394	171	1	1	1	1	1	1	1	2134276.79	923133	212	1	1	1	1	1	1	1	2050278.313	947503.2316
131	1	2	2	2	2	2	2	2064595.89	885572.247	172	1	2	2	2	2	2	2	2045884.81	878410.408	213	1	1	1	1	2	1	1	2075339.454	896874.8916
132	1	1	1	1	1	1	1	2026617.03	946924.703	173	1	2	2	1	1	2	1	2042739.19	920506.777	214	1	2	2	2	2	2	2	2061504.621	911144.0435
133	1	2	2	2	2	2	2	2041075.45	922458.736	174	1	1	2	1	1	2	1	2055033.92	885765.192	215	1	2	2	2	1	2	2	2079824.287	910553.5659
134	1	1	1	1	2	1	1	2026063.32	944287.98	175	1	1	2	2	1	2	2	2067397.42	943456.212	216	1	2	2	2	2	2	2	2053217.146	923584.6554
135	1	2	2	1	2	2	1	2068229.66	931827.328	176	1	2	1	2	2	2	2	2075987.19	919915.796	217	1	1	1	1	1	1	1	2079179.944	902820.6062
136	1	1	1	1	1	1	1	2080297.18	931438.422	177	1	1	1	1	1	1	1	2117710.94	928066.988	218	1	1	1	1	2	1	1	2084932.381	917692.7374
137	1	1	1	1	1	1	1	2063770.17	940552.81	178	1	1	1	1	1	1	1	2069924.61	925724.665	219	1	2	2	2	2	2	2	2043770.726	898289.192
138	1	2	1	1	2	1	1	2073100.77	895661.559	179	1	1	1	1	2	1	2	2052451.25	875465.432	220	1	1	1	2	1	1	2	2060773.354	909169.0809
139	1	2	2	1	2	2	1	2135884.14	931336.642	180	1	1	1	2	1	1	2	2035423.76	939991.227	221	1	1	1	1	1	1	1	2080089.963	913999.9201
140	1	2	2	2	2	1	2	2044492.45	925451.918	181	1	2	1	2	2	1	1	2045167.02	896277.651	222	1	2	2	2	2	2	2	2087903.958	927042.9103
141	1	1	2	1	1	2	1	2047226.66	930316.613	182	1	2	2	2	2	2	2	2054082.16	895994.376	223	1	1	2	1	1	2	1	2058503.715	909727.2102
142	1	1	1	1	1	2	1	2088644.9	918487	183	1	1	1	1	1	1	1	2061304.71	946300.052	224	1	2	2	2	2	2	1	2058203.583	898141.3054
143	1	2	2	2	2	2	2	2051253.88	912947.484	184	1	2	2	2	2	2	2	2098357.93	927915.984	225	1	1	1	1	1	1	1	2093734.994	934751.743
144	1	1	1	1	1	1	1	2068927.03	939941.651	185	1	1	1	1	1	1	1	2074354.78	934113.66	226	1	1	1	1	1	1	1	2082279.48	929971.0923
145	1	1	1	2	1	2	2	2048532.93	911599.359	186	1	2	2	2	2	2	2	2060507.95	925950.674	227	1	1	1	1	1	1	1	2054735.204	923093.3514
146	1	1	1	1	2	1	1	2081955.8	933050.978	187	1	1	1	1	2	1	2	2046703.75	873387.992	228	1	2	2	2	2	2	2	2048903.083	945223.2383
147	1	1	1	1	2	1	1	2093436.87	924246.655	188	1	2	2	2	2	2	2	2047899.67	932142.711	229	1	1	1	1	1	1	2	2076799.561	893986.7333
148	1	1	1	1	1	1	1	2064265.7	882937.717	189	1	1	1	1	2	1	1	2057439.07	893001.217	230	1	1	1	1	1	1	1	2075824.095	907747.5533
149	1	1	1	1	1	1	1	2023724.41	939345.881	190	1	1	1	1	1	1	1	2093906.86	939033.037	231	1	1	1	1	1	2	1	2128836.113	930246.1992
150	1	1	1	1	1	1	1	2051559.08	905070.691	191	1	1	1	1	1	1	1	2093650.7	939146.643	232	1	1	1	1	1	1	1	2067352.753	912648.3915
151	1	2	2	2	2	2	1	2082704.63	927245.133	192	1	2	2	2	2	2	2	2078097.08	895118.228	233	1	2	2	1	2	2	1	2045556.413	948573.8906
152	1	1	2	2	1	2	2	2052835.36	875880.454	193	1	1	2	1	1	2	1	2053745.09	918299.342	234	1	2	2	2	2	2	2	2064116.608	909493.4632
153	1	1	1	1	1	1	1	2125443.77	930567.981	194	1	1	2	2	1	2	2	2065949.37	887449.616	235	1	1	1	1	2	1	1	2026006.116	943295.9542
154	1	1	1	1	1	2	1	2077992.46	922008.584	195	1	2	2	2	2	2	2	2074139.74	898309.728	236	1	1	1	1	1	1	1	2073860.951	932779.0593
155	1	2	2	2	2	2	2	2062560.93	918506.968	196	1	1	1	1	1	1	1	2090556.2	938528.874	237	1	1	1	1	1	1	1	2067323.092	899408.3235
156	1	2	1	2	2	1	2	2041022.9	908699.183	197	1	2	2	2	2	2	2	2050598.07	911865.703	238	1	2	2	2	2	2	2	2041274.483	923666.1441
157	1	1	1	1	1	1	1	2085389.4	918766.923	198	1	1	1	1	1	1	1	2018553.13	949560.961	239	1	2	2	2	2	2	2	2050287.929	932094.2369
158	1	2	1	2	2	1	2	2074362.06	921351.038	199	1	1	2	2	1	1	2	2058921.03	948894.264	240	1	2	2	2	2	2	2	2076083.676	900872.3525
159	1	1	1	1	1	1	1	2105273.03	933145.504	200	1	2	2	1	2	2	1	2072237.95	929026.389	241	1	1	1	1	1	2	1	2078931.081	937143.5516
160	1	1	1	1	1	1	1	2022695.59	940607.984	201	1	2	2	2	2	2	2	2053042.84	927833.175	242	1	1	1	1	1	1	1	2051849.025	924859.1712
161	1	2	2	2	2	2	2	2113655.34	934703.363	202	1	2	2	2	2	2	2	2043850.73	916791.26	243	1	1	1	1	1	1	1	2044802.608	948731.8603
162	1	1	1	1	1	1	1	2077451.87	938370.913	203	1	1	1	1	1	1	1	2038431.9	927552.842	244	1	1	2	1	2	2	1	2040058.011	925518.6166
163	1	2	2	2	2	2	2	2052251.79	870135.609	204	1	1	1	1	1	1	1	2079132.81	933645.515	245	1	2	2	2	2	2	2	2062480.733	906967.288

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
246	1	1	1	1	1	1	2	2068341.62	897173.946
247	1	2	2	2	2	2	2	2053089.81	923621.562
248	1	1	1	1	1	1	1	2057855.65	936331.975
249	1	2	2	2	2	2	2	2074194.85	933419.694
250	1	2	2	2	2	2	2	2062936.95	929610.639
251	1	1	2	1	1	2	2	2097260.96	935405.547
252	1	2	2	2	2	2	2	2074485.22	929547.741
253	1	1	1	1	1	2	2	2120315.37	931567.158
254	1	2	2	2	2	2	2	2048616.42	908498.402
255	1	2	2	2	2	2	2	2053917.75	915723.98
256	1	1	1	1	1	1	2	2120400.2	931861.839
257	1	1	1	1	1	1	1	2038970.24	922185.275
258	1	1	1	1	2	1	1	2117204.37	937256.21
259	1	2	2	1	2	1	1	2079521.08	912561.989
260	1	1	1	1	1	1	1	2078550.88	926687.078
261	1	1	1	1	2	2	1	2034982.68	934396.527
262	1	2	2	2	2	2	2	2061714.64	886190.522
263	1	1	1	1	1	1	1	2126656.03	930591.851
264	1	1	1	1	1	1	2	2085095.73	935590.198
265	1	2	2	2	2	2	2	2049844.34	892242.277
266	1	1	1	1	1	1	1	2019288.37	944796.062
267	1	1	1	1	1	1	2	2098121.16	936959.161
268	1	1	1	1	1	2	1	2091497.59	937075.07
269	1	1	1	1	1	1	1	2044443.69	939316.872
270	1	1	1	1	1	1	1	2073620.53	902211.642
271	1	2	2	2	2	2	2	2071999.56	923725.611
272	1	1	1	1	1	1	1	2131784.31	925663.928
273	1	1	1	1	1	1	1	2084881.46	912341.226
274	1	2	1	1	2	1	1	2056078.4	934812.066
275	1	1	1	1	1	1	1	2066972.8	887791.641
276	1	2	1	2	2	1	1	2049747.84	918718.889
277	1	2	2	2	2	2	2	2041544.15	894718.146
278	1	2	2	2	1	2	2	2067411.32	895212.087
279	1	1	2	1	1	2	2	2083227.27	926613.502
280	1	1	1	2	1	1	2	2099691.34	934815.449
281	1	1	2	1	1	2	1	2060914.64	915448.27
282	1	2	2	2	2	2	2	2043979.26	912758.564
283	1	1	1	1	1	1	1	2081167.78	912803.495
284	1	2	2	2	2	2	2	2049081.67	893251.654
285	1	2	2	2	2	2	2	2040895.66	896226.688
286	1	2	2	2	2	2	2	2059859.33	943692.659

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
287	1	1	1	1	1	1	1	2107073.05	939204.007
288	1	1	1	1	1	1	1	2108104.09	929409.422
289	1	1	1	1	1	1	1	2048565.41	942698.762
290	1	1	1	1	2	1	1	2089398.21	935006.935
291	1	1	1	1	2	1	1	2041299.12	928685.392
292	1	2	2	2	2	2	2	2038063.87	920256.246
293	1	2	2	2	1	2	2	2043947.39	925166.008
294	1	1	1	1	1	1	1	2031220.54	936835.376
295	1	1	1	1	2	1	1	2090162.12	923775.599
296	1	2	2	2	2	2	2	2063250.31	934839.833
297	1	1	1	1	1	1	1	2133072.92	931574.546
298	1	2	1	1	2	1	1	2076535.82	915690.853
299	1	1	1	1	2	1	1	2081735.94	906895.687
300	0	2	2	2	2	2	2	2076919.33	918101.942
301	0	1	1	1	1	2	1	2041041.66	931051.436
302	0	1	1	1	1	1	1	2062606.06	937959.391
303	0	1	1	1	1	1	1	2066667.38	946626.746
304	0	1	1	1	1	1	1	2097552.18	933884.016
305	0	2	2	2	2	2	2	2042166.61	900691.468
306	0	2	2	1	2	2	2	2095666.17	926334.079
307	0	2	1	2	2	1	2	2068697.05	919269.532
308	0	2	2	2	2	2	2	2066671.1	911844.684
309	0	1	1	1	1	1	1	2068033.59	914801.707
310	0	1	1	1	1	1	1	2035041.53	948931.098
311	0	2	2	2	2	2	2	2054368.08	918863.025
312	0	2	2	2	2	2	2	2065362.28	901654.948
313	0	1	1	1	1	1	1	2061066.12	918818.796
314	0	1	1	1	1	1	1	2079068	897742.568
315	0	2	2	2	2	2	2	2062569.17	932923.127
316	0	1	1	1	1	1	1	2082660.74	909432.706
317	0	1	1	1	1	1	1	2082398.8	914071.06
318	0	2	2	2	1	2	2	2055150.73	940718.469
319	0	2	2	2	2	2	2	2057115.17	884908.93
320	0	2	2	1	2	2	2	2041821.68	908242.433
321	0	1	1	1	1	1	1	2062556.84	941656.594
322	0	2	2	2	2	2	2	2074935.37	907149.362
323	0	1	1	1	1	1	2	2060879.45	883314.156
324	0	2	2	2	2	2	2	2046118.31	949001.855
325	0	2	1	1	2	1	1	2054038.04	943636.097
326	0	2	2	2	2	2	2	2068982.12	905028.789
327	0	1	2	2	1	2	2	2056874.87	921083.633

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
328	0	1	1	1	1	1	1	2061176.817	941028.8895
329	0	2	2	2	2	2	2	2051445.716	899000.0685
330	0	2	2	2	1	2	2	2091991.898	937031.165
331	0	2	2	2	2	2	2	2076164.014	921118.0163
332	0	1	1	1	1	1	1	2066330.009	904112.8235
333	0	1	1	1	1	1	1	2064093.064	943372.8938
334	0	1	1	1	1	2	2	2075072.962	923393.4118
335	0	1	1	1	1	1	1	2134106.461	925819.4825
336	0	2	2	2	2	2	2	2087139.355	927793.3738
337	0	2	2	2	2	2	1	2068884.693	903954.4369
338	0	1	2	2	1	2	2	2061165.64	887815.9559
339	0	2	2	2	2	2	2	2062871.683	919574.6471
340	0	2	2	2	1	2	2	2041751.702	895623.0753
341	0	1	2	1	1	2	1	2068769.736	882521.0781
342	0	1	1	1	1	1	1	2037808.604	944413.4508
343	0	1	1	1	1	1	1	2056441.917	941351.5397
344	0	1	1	1	1	1	1	2070279.808	940046.3926
345	0	1	1	1	1	1	1	2054042.811	882769.389
346	0	1	1	1	1	1	1	2055928.019	895179.5972
347	0	1	1	1	1	1	1	2124860.832	934886.8827
348	0	2	2	2	2	2	2	2062427.78	887654.3331
349	0	2	2	2	2	2	2	2050821.38	899906.3896
350	0	1	2	2	1	2	2	2095510.269	928125.7596
351	0	1	1	1	1	1	1	2034622.123	948601.5025
352	0	1	1	1	1	1	1	2036687.993	930071.5102
353	0	1	1	2	1	1	2	2050923.075	871226.5484
354	0	1	1	1	1	1	1	2124249.811	928324.2259
355	0	1	1	1	1	1	1	2028465.957	946235.4431
356	0	2	2	2	2	2	2	2082390.196	932367.9842
357	0	2	2	2	2	2	2	2055593.379	909641.6672
358	0	2	1	2	2	1	2	2070991.531	917512.6625
359	0	1	1	1	1	1	1	2126203.701	926799.8904
360	0	1	1	1	1	1	1	2042767.958	948512.6248
361	0	1	2	2	1	2	2	2085254.015	908302.9013
362	0	2	2	2	2	2	2	2056348.851	910460.8924
363	0	1	1	1	1	1	1	2088800.08	929299.9763
364	0	1	1	2	1	1	2	2098409.023	925982.822
365	0	1	1	1	2	1	1	2083089.126	939592.0793
366	0	1	1	1	1	1	1	2019481.552	948869.149
367	0	1	1	1	1	1	1	2023319.303	939074.2988
368	0	2	2	2	2	2	2	2035948.795	920715.6937

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
369	0	2	2	2	2	2	2	2025306.46	942740.114
370	0	2	2	2	2	2	2	2050116.95	905177.581
371	0	1	1	1	2	1	1	2061925.22	876090.999
372	0	1	1	1	1	1	1	2070093.56	913415.525
373	0	2	2	2	2	2	1	2051046.86	887602.772
374	0	1	1	1	1	1	1	2030727.77	942851.804
375	0	2	2	2	2	2	2	2061794.71	882963.337
376	0	2	2	2	2	2	1	2066534.18	905302.786
377	0	2	1	1	2	1	2	2059874.89	887454.151
378	0	2	2	2	2	2	2	2054107.08	941054.189
379	0	2	2	1	2	1	1	2086540.98	931905.618
380	0	1	1	1	1	1	1	2047827.67	876089.996
381	0	2	2	2	2	2	1	2039023.96	927451.21
382	0	2	2	2	2	2	2	2047202.29	925181.949
383	0	2	2	2	2	2	2	2023121.83	936337.287
384	0	2	1	1	2	1	2	2076831.7	901757.411
385	0	1	1	1	2	1	1	2084395.35	935936.386
386	0	1	1	1	1	1	1	2105575.27	937468.842
387	0	1	2	1	1	1	1	2045230.69	934137.37
388	0	1	1	1	1	1	1	2059658.4	938491.181
389	0	2	2	2	2	2	2	2027437.77	932328.546
390	0	2	2	2	2	2	2	2083030.17	911817.143
391	0	2	2	2	2	2	2	2075856.18	917171.366
392	0	1	1	2	1	1	2	2068026.16	935820.055
393	0	2	2	2	2	2	2	2048822.44	948726.587
394	0	2	2	2	2	2	2	2058391.12	913259.066
395	0	1	1	1	1	1	1	2038595.86	924722.103
396	0	2	2	2	2	2	2	2123811.9	930040.928
397	0	2	2	2	2	2	2	2049207.35	893650.09
398	0	1	1	1	1	1	1	2051340.85	901732.273
399	0	2	2	2	2	2	2	2082907.02	935601.303
400	0	2	2	2	2	2	2	2046906.22	910165.167
401	0	2	2	2	2	2	2	2044192.39	909201.301
402	0	1	1	1	1	2	1	2052708.83	938639.045
403	0	1	1	1	1	1	1	2061274.47	880067.739
404	0	2	2	2	2	1	2	2047754.43	921559.508
405	0	2	2	2	2	2	2	2037878.93	921060.531
406	0	2	2	1	1	1	1	2080486.68	913346.195
407	0	1	1	1	1	1	1	2058462.9	938926.711
408	0	2	2	2	2	2	2	2079228.86	907769.819
409	0	1	1	2	1	1	2	2127796.35	926553.499

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
410	0	1	1	2	1	1	2	2062764.09	929797.182
411	0	1	1	1	1	1	1	2092384.15	934469.755
412	0	2	2	2	2	2	2	2044407.73	869680.918
413	0	1	1	1	1	1	1	2046881.23	928370.067
414	0	1	1	1	2	1	1	2117441.52	939448.505
415	0	2	2	2	2	2	2	2042164.7	914801.697
416	0	1	1	2	1	1	2	2083448.93	923606.125
417	0	2	1	1	2	1	1	2113798.92	932181.62
418	0	2	2	2	2	2	2	2064013.44	916400.911
419	0	1	1	1	1	1	1	2072616.65	912788.84
420	0	1	1	1	1	1	1	2131562.79	924809.943
421	0	1	1	1	1	1	1	2019233.22	941273.799
422	0	1	1	1	1	1	1	2030300.76	948217.728
423	0	2	2	2	2	2	2	2042073.98	906069.201
424	0	1	1	1	1	1	1	2069778.87	939573.194
425	0	1	1	1	1	1	1	2061939.9	899917.78
426	0	2	2	2	2	2	2	2072399.58	925728.647
427	0	2	1	1	2	1	1	2126139.97	939832.52
428	0	2	1	1	2	2	1	2114144.44	932073.364
429	0	1	1	1	2	1	1	2099238.95	926169.17
430	0	2	2	2	2	2	2	2045796.67	923885.098
431	0	1	2	2	1	2	1	2039058.14	925992.056
432	0	2	2	2	2	2	2	2043780.36	902553.974
433	0	2	2	1	2	1	1	2096790.37	937804.345
434	0	1	1	1	2	1	1	2094899.36	936188.616
435	0	1	1	1	1	1	1	2095420.16	940168.018
436	0	2	2	2	2	2	2	2070416.21	892430.696
437	0	1	2	2	1	2	2	2063496.81	883160.511
438	0	2	2	1	2	2	1	2080388.58	918854.179
439	0	1	1	1	1	1	1	2124239.06	925663.862
440	0	1	1	1	1	1	1	2057879.82	887807.227
441	0	2	2	2	2	2	2	2100364.14	927438.636
442	0	2	2	2	2	2	2	2028658.28	931227.659
443	0	1	1	1	2	1	1	2050692.38	887666.543
444	0	2	2	2	2	2	2	2091813.69	923994.342
445	0	2	2	2	2	2	2	2096395.6	937875.4
446	0	1	2	1	1	1	1	2084843.15	914306.111
447	0	2	2	2	2	2	2	2058339.12	879167.71
448	0	2	2	2	2	2	2	2072160.58	883982.696
449	0	1	1	1	1	1	1	2054777.94	945459.139
450	0	2	2	2	2	2	2	2083432.9	903527.54

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
451	0	2	1	2	1	1	2	2138242.974	926975.7585
452	0	1	1	1	1	1	1	2071000.385	917385.8432
453	0	2	2	2	2	2	2	2084416.29	940296.6563
454	0	2	2	2	2	2	2	2043162.171	904905.703
455	0	2	2	2	1	1	2	2072926.278	911702.7447
456	0	2	2	2	2	2	2	2062542.002	919194.0238
457	0	1	1	1	1	1	1	2027177.034	943860.4346
458	0	2	2	2	2	2	2	2079616.989	935148.6911
459	0	1	1	1	1	1	1	2121630.448	936417.673
460	0	2	2	2	2	2	2	2092562.406	926401.9294
461	0	2	2	2	2	2	2	2062969.241	928768.7682
462	0	2	2	2	2	2	2	2069142.972	904460.38
463	0	1	2	1	2	2	1	2034053.61	940209.7168
464	0	2	1	1	2	1	1	2130247.296	938266.5528
465	0	2	1	2	1	1	2	2069365.549	888600.9191
466	0	2	2	2	2	2	2	2078770.775	925837.5763
467	0	1	2	1	2	2	1	2045846.479	909914.4568
468	0	2	2	2	2	2	2	2066530.849	898588.9317
469	0	2	2	2	1	2	2	2088691.384	927028.1372
470	0	1	1	1	1	2	1	2061072.979	895349.3309
471	0	1	1	1	1	1	1	2058036.263	907347.2391
472	0	2	2	2	1	2	2	2055835.388	944191.9776
473	0	1	1	1	2	1	2	2073091.589	898832.2295
474	0	1	1	1	1	1	1	2050905.94	890981.418
475	0	1	1	1	1	1	2	2039666.142	924060.5582
476	0	1	1	1	1	1	1	2043119.684	944432.846
477	0	1	2	2	1	2	1	2066674.559	882081.7832
478	0	1	1	1	1	1	1	2065172.02	903764.9945
479	0	2	2	1	2	2	1	2072149.355	935634.9987
480	0	1	1	1	1	1	1	2065841.409	926977.6467
481	0	2	2	2	2	2	2	2077031.564	933587.1453
482	0	2	2	2	2	2	2	2070486.94	925945.4514
483	0	2	1	1	2	1	2	2073829.572	927311.5139
484	0	1	1	1	2	1	1	2032455.475	927724.5001
485	0	2	2	2	2	2	2	2043984.138	907126.8481
486	0	1	2	2	1	2	2	2053690.588	875517.6354
487	0	2	2	1	2	1	1	2133602.964	940000.3355
488	0	1	1	1	2	1	1	2038082.804	941497.9122
489	0	1	1	1	1	1	1	2098296.122	927522.3911
490	0	1	1	1	1	1	1	2081237.363	940067.365
491	0	2	2	2	2	2	2	2092439.785	939102.5679

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
492.	0	2	2	2	1	2	1	2063662.37	899604.266
493	0	2	2	2	2	2	2	2119698.7	934384.191
494	0	1	1	1	1	1	1	2064400.11	876602.782
495	0	1	1	1	1	2	1	2035678.2	933809.469
496	0	1	2	2	1	2	2	2054863.37	901415.1
497	0	1	1	1	1	1	1	2086567.22	905152.707
498	0	2	1	2	2	1	2	2040866.05	923672.447
499	0	2	2	1	2	1	1	2132126.96	937692.345
500	0	2	2	2	2	2	2	2070925.71	894268.037
501	0	1	2	2	2	2	2	2060730.62	932132.914
502	0	2	2	2	2	2	2	2060441.12	888147.851
503	0	1	1	1	1	1	1	2025318.14	939768.542
504	0	1	1	1	1	1	1	2114769.82	939225.828
505	0	1	1	1	1	1	1	2077947.23	939202.822
506	0	1	2	1	1	2	2	2066050.71	936362.801
507	0	1	1	1	1	1	1	2079389.28	912204.149
508	0	2	2	2	2	2	2	2059519.49	911246.069
509	0	1	1	1	1	1	1	2053818.54	905537.347
510	0	1	1	1	1	1	1	2095859.76	938459.734
511	0	2	2	2	2	2	2	2079041.99	910517.431
512	0	1	1	1	1	1	1	2059553.46	928724.515
513	0	2	2	2	1	2	2	2050802.82	893745.369
514	0	2	2	2	2	2	2	2082267.95	908436.005
515	0	1	2	1	1	2	1	2046653.21	901163.031
516	0	1	1	1	1	1	1	2047527.03	942923.415
517	0	1	2	2	1	2	2	2046780.23	943943.309
518	0	1	1	1	1	1	1	2086217	940212.338
519	0	1	1	1	1	1	1	2062119.9	942464.578
520	0	2	2	2	2	2	2	2047672.53	894409.845
521	0	1	1	1	2	1	1	2038811.3	922498.845
522	0	2	2	2	2	2	2	2070306.4	888695.169
523	0	2	2	2	2	2	1	2050508.12	911537.652
524	0	2	2	2	2	2	2	2055015.33	912688.448
525	0	1	1	1	1	1	1	2045767.87	926883.635
526	0	1	1	1	1	1	1	2059137.19	945885.814
527	0	1	1	1	1	1	1	2035437.97	938445.055
528	0	1	1	1	1	1	1	2049333.09	892675.79
529	0	2	2	2	2	2	2	2138565.15	927617.704
530	0	1	1	1	1	1	1	2073793.64	904775.197
531	0	1	1	1	1	1	1	2106159.46	938416.688
532	0	2	2	2	2	2	2	2020762.52	938919.638

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
533	0	2	2	1	2	2	1	2046022.5	938743.471
534	0	1	1	1	1	1	1	2026772.86	935549.756
535	0	1	1	1	1	1	2	2058201.11	880836.787
536	0	1	1	1	1	1	1	2047970.75	946953.331
537	0	1	1	1	1	1	1	2058118.49	875451.741
538	0	2	2	2	2	2	2	2043806.94	922800.42
539	0	2	1	2	2	1	2	2042071.1	906997.594
540	0	2	2	2	2	2	2	2063483.21	917840.447
541	0	1	2	2	1	1	2	2123659.19	926548.826
542	0	2	2	2	2	2	2	2044723.46	900096.703
543	0	2	2	2	2	1	2	2046533.98	875298.087
544	0	1	1	1	1	1	1	2061738.99	935682.578
545	0	1	1	1	2	1	1	2038497.97	935214.492
546	0	1	1	1	1	1	1	2050699.1	904823.732
547	0	1	1	1	1	1	1	2077552.2	933215.442
548	0	1	1	1	1	1	1	2065328.47	946487.51
549	0	1	1	1	1	1	1	2053954.63	946640.43
550	0	2	2	2	2	2	2	2043936.48	915055.678
551	0	1	2	2	1	2	2	2056403.18	881797.457
552	0	2	2	2	2	2	2	2092589.73	926334.331
553	0	1	2	2	1	2	2	2042248.03	928006.974
554	0	1	1	1	1	2	1	2060169.35	932353.647
555	0	1	1	1	2	1	1	2033996.73	928244.577
556	0	1	1	1	1	1	1	2068713.85	900000.195
557	0	1	1	1	1	1	1	2036743.63	928519.327
558	0	2	2	2	2	2	2	2049792.51	926573.196
559	0	1	1	1	1	1	1	2084233.16	939862.361
560	0	2	2	2	2	2	2	2044411.86	943659.75
561	0	2	2	2	1	2	2	2111145.55	929085.455
562	0	2	2	2	2	2	2	2076710.6	911434.561
563	0	2	1	1	2	1	1	2131135.88	939915.837
564	0	2	2	2	2	2	2	2084653.64	915133.701
565	0	1	1	1	1	1	1	2095317.45	926289.332
566	0	1	1	1	1	1	1	2105356.89	938367.338
567	0	1	2	2	1	2	2	2098787.67	934278.812
568	0	1	2	1	2	2	1	2045339.38	896449.768
569	0	1	1	1	1	1	1	2106036.21	928824.505
570	0	1	1	1	1	1	1	2081054.14	925262.581
571	0	1	1	1	1	1	1	2040464.66	938863.972
572	0	1	1	1	1	1	1	2058913.89	905737.91
573	0	1	1	1	1	1	1	2062105.97	929538.959

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
574	0	2	2	2	2	2	2	2059352.255	928100.8123
575	0	2	2	2	2	2	2	2041706.501	896812.2751
576	0	2	2	2	2	2	2	2066264.165	902798.1456
577	0	1	1	1	1	1	1	2037322.862	932034.7444
578	0	1	1	1	1	1	1	2051688.51	904634.4057
579	0	1	1	1	1	1	1	2053398.865	883867.3296
580	0	2	2	2	2	2	2	2083125.887	934265.4776
581	0	1	1	1	1	1	1	2053049.928	876005.7214
582	0	1	2	1	1	1	1	2052317.857	879332.4229
583	0	1	1	1	1	1	1	2055496.725	905896.8121
584	0	1	1	1	1	1	1	2067889.068	918353.8246
585	0	2	2	2	2	2	2	2123130.012	940070.1607
586	0	2	2	2	2	2	2	2057781.929	911591.0179
587	0	2	2	2	2	2	2	2059209.855	921743.8369
588	0	2	2	2	2	2	2	2048982.605	920891.6554
589	0	1	1	1	1	1	1	2050452.219	949066.5561
590	0	2	2	2	2	2	2	2046332.389	894759.5899
591	0	1	1	1	2	1	1	2039861.859	946719.44
592	0	2	2	2	2	2	2	2095512.626	926498.572
593	0	1	1	1	2	1	1	2033726.723	934713.8286
594	0	1	1	1	1	1	1	2044315.318	926380.5258
595	0	1	1	2	1	1	2	2047541.84	927680.5362
596	0	2	2	2	2	2	2	2055861.791	923528.2009
597	0	2	2	2	2	2	2	2079762.959	924758.6044
598	0	1	1	1	1	1	1	2048364.172	896537.5143
599	0	2	2	2	2	2	2	2048525.16	945330.303
600	0	2	2	2	2	2	2	2098344.729	925860.3959
601	0	1	1	1	1	1	1	2066872.123	921688.0919
602	0	1	1	2	1	1	2	2059681.163	940804.3804
603	0	1	1	1	1	1	1	2117540.988	939011.2905
604	0	2	2	2	1	2	2	2054100.412	892153.0111
605	0	1	1	1	1	2	1	2037630.559	943087.9216
606	0	1	1	1	1	1	1	2066550.605	921852.8329
607	0	2	2	2	2	2	2	2077756.494	924264.2505
608	0	1	1	1	1	1	1	2035764.214	933949.2466
609	0	2	2	2	2	2	2	2057928.792	927261.7084
610	0	1	1	1	2	1	2	2093859.944	936873.1284
611	0	2	2	2	2	2	2	2031424.421	927363.6065
612	0	1	1	1	1	1	1	2026305.206	935193.406
613	0	2	2	2	2	2	2	2048160.769	923762.6986
614	0	1	1	1	1	1	1	2044470.32	945510.134

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
615	0	2	2	2	2	2	2	2079000.31	902234.975
616	0	1	1	1	1	1	1	2125118.42	925190.532
617	0	1	1	1	1	1	1	2132594.71	923242.721
618	0	2	2	2	2	2	2	2051543.2	883241.701
619	0	1	1	1	1	2	1	2061953.58	885108.392
620	0	1	1	1	1	2	1	2041687.21	929998.192
621	0	2	1	1	2	1	1	2097663.37	931880.96
622	0	2	2	2	2	2	2	2048257.84	923731.235
623	0	1	1	1	1	1	1	2125460.35	927521.359
624	0	1	1	2	1	1	2	2056987.88	933895.919
625	0	1	2	1	1	2	1	2074707.81	917061.232
626	0	1	1	1	1	1	1	2056735.67	938840.271
627	0	1	1	1	1	1	1	2054093.91	899820.01
628	0	2	2	2	2	2	2	2066936.7	889096.83
629	0	1	1	1	1	1	1	2060612.77	898301.778
630	0	2	2	2	2	2	2	2068620.56	892277.706
631	0	1	1	1	1	1	1	2025827.23	943973.835
632	0	1	1	1	1	1	1	2074440.81	897141.761
633	0	1	2	1	1	2	1	2045044.47	929085.11
634	0	1	1	1	2	1	1	2075580.74	926883.977
635	0	2	2	2	2	2	2	2068775.22	927366.316
636	0	2	2	2	2	2	2	2056526.96	909428.503
637	0	2	2	2	2	2	2	2051523.88	916618.346
638	0	1	1	1	1	1	1	2017698.83	947855.424
639	0	1	1	1	1	1	1	2058430.74	875267.938
640	0	1	1	1	1	1	1	2068006.87	909629.501
641	0	2	2	2	2	2	2	2051863.03	929227.332
642	0	1	1	1	1	1	1	2131127.49	936897.672
643	0	1	1	1	1	1	1	2075636.11	912392.375
644	0	1	1	1	1	1	2	2067186.35	910975.042
645	0	2	2	2	2	2	2	2057866.28	880994.727
646	0	2	2	2	2	2	2	2046145.45	895359.063
647	0	2	2	2	2	2	2	2069198.13	927366.014
648	0	2	2	2	2	2	2	2043137.8	904691.454
649	0	2	2	2	2	2	2	2057986.44	902127.148
650	0	2	2	2	2	2	2	2047426.99	910760.274
651	0	2	2	2	2	2	2	2046152.48	913136.087
652	0	1	1	2	1	1	2	2051845.71	890212.44
653	0	2	2	1	1	1	1	2089129.3	928111.071
654	0	2	2	2	2	2	2	2096899.03	939416.721
655	0	1	1	1	1	1	1	2045707.81	875862.796

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
656	0	1	1	1	1	1	1	2066091.35	946810.07
657	0	2	2	2	2	2	2	2084925.03	936532.165
658	0	1	1	1	1	1	1	2068866.22	908960.497
659	0	2	2	2	2	2	2	2053618.07	923412.651
660	0	1	1	1	1	1	1	2127755.02	929740.594
661	0	2	2	2	2	2	2	2058507.03	911808.758
662	0	1	2	1	1	2	1	2128727.48	931746.79
663	0	2	1	1	2	1	1	2081323.23	922748.489
664	0	1	1	1	1	1	1	2028025.27	938888.146
665	0	2	2	2	2	2	2	2053165.74	878338.977
666	0	1	1	1	1	1	1	2040052.31	948708.696
667	0	1	1	1	1	1	1	2118496	928252.619
668	0	1	1	1	2	1	1	2036478.12	939007.451
669	0	1	1	2	1	1	2	2037162.9	948398.828
670	0	1	1	1	1	2	2	2061092.75	891908.688
671	0	1	1	1	1	1	1	2022407.26	943055.035
672	0	1	1	1	1	1	1	2066325.99	903922.835
673	0	1	1	1	1	1	1	2083465.15	922380.297
674	0	2	2	2	1	2	1	2060264.46	927562.183
675	0	2	2	2	2	2	2	2071372.75	896345.776
676	0	1	1	1	1	1	1	2083136.98	933540.066
677	0	1	1	1	1	1	1	2135935.25	928866.361
678	0	2	2	2	2	2	2	2063597.97	915347.723
679	0	2	2	2	2	2	2	2058990.89	921328.136
680	0	1	1	1	1	1	1	2062032.07	937820.18
681	0	1	1	2	1	1	2	2062550.66	945266.379
682	0	1	1	1	2	1	2	2112781.25	930137.379
683	0	1	1	1	1	2	1	2057291.37	894308.584
684	0	1	1	2	1	1	2	2060751.46	934847.461
685	0	2	2	2	2	2	2	2069428.05	933122.44
686	0	1	1	1	1	1	1	2058923.57	937090.089
687	0	2	2	2	2	2	2	2093032.94	936625.993
688	0	2	2	1	2	2	1	2057588.06	905379.525
689	0	2	2	1	2	1	1	2088484.67	914442.005
690	0	1	1	1	1	1	1	2140871.7	932058.818
691	0	1	1	1	1	1	1	2061912.77	931851.26
692	0	1	1	1	1	1	1	2040236.85	935191.796
693	0	2	1	1	2	1	2	2103755.25	929613.489
694	0	1	1	1	1	1	2	2052604.46	919111.066
695	0	2	2	2	2	2	2	2064030.58	919040.749
696	0	2	2	2	1	2	2	2046772.08	926624.23

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
697	0	1	1	1	1	1	1	2067161.156	944084.1973
698	0	1	1	2	2	1	2	2061529.568	908958.1133
699	0	2	2	2	2	2	2	2064463.414	889589.9692
700	0	1	1	1	1	1	1	2077204.591	937424.7359
701	0	2	2	2	2	2	2	2062609.717	884688.798
702	0	2	2	2	2	2	2	2047189.149	923974.3315
703	0	2	2	2	2	2	2	2046754.84	874883.9349
704	0	2	2	2	2	2	2	2035997.355	921308.2152
705	0	1	1	1	1	1	1	2035124.091	931608.8715
706	0	1	1	1	2	1	1	2109904.403	931309.2463
707	0	1	2	2	1	2	2	2131224.885	932909.6755
708	0	1	1	1	1	1	1	2126515.893	930025.1547
709	0	2	2	2	1	2	2	2059174.569	880573.4369
710	0	2	2	2	2	2	2	2033525.747	926379.8876
711	0	1	1	1	2	1	1	2083346.639	917700.5939
712	0	2	2	2	2	2	2	2056696.4	923104.9441
713	0	2	2	2	2	2	2	2089904.634	928005.6021
714	0	2	2	2	2	2	2	2056259.293	893703.07
715	0	1	1	1	1	1	1	2081008.997	918556.1477
716	0	1	1	1	1	2	1	2083496.703	927096.1986
717	0	1	1	1	1	1	1	2127903.949	927995.9798
718	0	1	1	1	1	1	1	2045819.157	937022.3422
719	0	1	2	2	1	2	2	2061570.578	881677.2926
720	0	2	2	2	2	2	2	2074088.321	928119.5565
721	0	1	1	1	1	1	1	2051250.779	901018.0931
722	0	1	1	1	1	1	1	2048425.454	909393.2945
723	0	1	1	1	2	1	1	2110307.226	932665.6404
724	0	2	2	2	2	2	2	2113398.439	934298.8406
725	0	1	1	1	1	1	1	2072323.844	885784.5961
726	0	1	1	1	1	1	1	2080273.455	912335.8527
727	0	2	2	2	2	2	2	2073158.649	902283.8375
728	0	2	2	2	2	2	2	2067141.109	887937.9614
729	0	2	2	2	1	2	2	2068882.344	918291.7169
730	0	2	2	2	2	2	2	2078130.696	920746.7238
731	0	1	1	1	1	1	2	2042759.63	895624.6895
732	0	1	1	1	1	1	1	2077020.219	931683.9333
733	0	2	1	1	2	1	1	2131014.335	938489.067
734	0	1	1	1	2	1	1	2066524.755	946252.4617
735	0	1	1	1	1	1	1	2035812.752	934412.7189
736	0	2	2	1	2	2	1	2049663.773	897413.7221
737	0	2	2	2	2	2	2	2081208.363	933512.0858

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
738	0	1	1	1	2	1	1	2135343.34	928316.396
739	0	1	1	1	1	1	1	2118552.15	929125.349
740	0	1	2	2	1	1	1	2053229.07	889234.558
741	0	2	2	2	2	2	2	2046873.12	892178.121
742	0	2	2	2	2	2	2	2038934.62	917176.718
743	0	2	2	2	2	2	1	2039880.93	929535.391
744	0	2	2	2	2	2	2	2049377.12	936110.716
745	0	1	1	1	1	1	1	2037368.48	922554.668
746	0	2	2	2	2	2	2	2044001.18	897018.163
747	0	2	2	2	2	2	2	2058059.32	916111.607
748	0	2	2	2	2	2	2	2045127.54	922705.756
749	0	1	1	2	1	2	2	2028404.68	932837.866
750	0	2	2	2	2	2	2	2025855.27	934557.244
751	0	1	1	1	1	1	1	2026243.37	948261.231
752	0	1	1	1	1	1	1	2029660.73	938815.209
753	0	1	1	1	1	1	2	2040901.63	940836.046
754	0	2	2	2	2	2	2	2060378.55	879747.494
755	0	2	2	2	2	2	2	2044700.7	903110.497
756	0	2	2	1	1	1	1	2049464.46	907475.502
757	0	1	1	1	2	1	1	2085013.04	907962.689
758	0	1	1	1	1	1	1	2053930.01	905803.863
759	0	2	2	2	2	2	2	2049051.69	922184.091
760	0	2	1	1	2	1	1	2045645.77	944383.895
761	0	1	1	1	1	1	1	2078557.23	896670.915
762	0	1	1	1	1	1	1	2134742.49	927160.97
763	0	1	1	1	1	1	1	2041308.44	929815.809
764	0	1	1	1	1	1	1	2118510.62	930592.143
765	0	2	2	2	2	1	2	2054789.01	896164.353
766	0	1	1	1	1	2	1	2079386.39	936610.374
767	0	2	2	2	2	2	2	2067077.27	909383.602
768	0	2	2	2	2	2	2	2049562.71	939893.885
769	0	2	2	2	2	2	2	2045962.45	904051.407
770	0	2	2	2	2	2	2	2054210.26	917437.874
771	0	1	1	1	1	1	1	2042361.67	946602.678
772	0	2	2	2	2	2	2	2071579.55	896853.79
773	0	2	2	2	2	2	2	2067611.06	919217.01
774	0	1	2	2	1	2	2	2094789.32	926589.976
775	0	2	1	1	2	1	2	2084951.2	907187.832
776	0	2	2	2	2	2	2	2069484.81	906206.2
777	0	1	1	1	1	1	1	2027139.54	936792.522
778	0	1	1	1	1	1	1	2054706.48	935371.743

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
779	0	1	1	1	2	1	1	2035673.39	934242.248
780	0	1	1	1	1	2	1	2040587.27	934131.85
781	0	1	1	1	1	1	1	2053129.98	925663.285
782	0	2	2	2	2	2	2	2081295.95	930495.387
783	0	2	1	2	2	1	2	2057242.81	897053.298
784	0	2	1	1	2	1	2	2081955.48	921614.254
785	0	2	2	2	2	2	2	2046358.47	875377.308
786	0	1	2	2	1	2	2	2067037.18	946218.919
787	0	2	2	2	2	2	2	2057993.88	906932.242
788	0	1	1	1	1	1	1	2100960.26	930050.115
789	0	2	2	2	2	2	2	2040561.67	912567.004
790	0	2	1	1	1	1	1	2033111.85	934478.632
791	0	2	2	2	2	2	2	2115322.35	929959.737
792	0	1	1	2	1	1	2	2064118.22	885580.281
793	0	1	1	1	1	1	1	2090073.18	923293.09
794	0	1	1	1	1	1	1	2019889.57	940433.098
795	0	1	1	1	1	1	2	2048973.42	944203.069
796	0	1	1	1	1	1	1	2066584.88	892375.208
797	0	2	1	1	2	1	1	2087709	918410.852
798	0	1	1	1	1	1	1	2050845.6	868580.309
799	0	1	1	1	2	1	1	2050022.35	940008.36
800	0	2	2	2	2	2	2	2054552.31	941770.818
801	0	1	2	2	1	2	2	2041051.92	917123.042
802	0	1	1	1	1	2	1	2054805.67	892301.062
803	0	1	1	1	1	1	1	2085714.48	936573.033
804	0	1	1	1	1	1	1	2084077.16	933120.241
805	0	1	1	2	1	1	2	2094231.7	927477.69
806	0	1	1	1	2	1	1	2089182.57	936091.594
807	0	1	1	2	1	2	2	2078790.81	930163.695
808	0	1	2	2	1	1	2	2093837.03	928227.682
809	0	2	2	2	2	2	2	2047908.78	908117.958
810	0	1	1	1	1	1	1	2055924.7	885908.432
811	0	2	2	2	2	2	2	2075949.4	933127.872
812	0	1	1	1	1	1	1	2018921.48	944028.933
813	0	1	1	1	1	1	1	2051524.08	875682.769
814	0	2	1	2	1	1	2	2083545.84	907172.147
815	0	2	2	1	2	1	1	2067977.83	938569.822
816	0	1	1	1	1	1	1	2130271.74	927686.199
817	0	1	2	1	2	1	1	2084170.77	918700.375
818	0	1	1	1	1	1	1	2052564.6	892963.752
819	0	1	1	1	1	1	1	2029566.91	939886.098

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
820	0	2	2	2	2	2	2	2041932.304	911077.4804
821	0	2	2	2	2	2	2	2066524.313	910425.7932
822	0	2	2	2	2	2	2	2073754.733	896956.286
823	0	1	1	1	1	2	1	2043615.629	928725.8116
824	0	1	1	1	1	1	1	2041928.38	939504.3429
825	0	2	2	2	2	1	2	2066377.871	900950.2485
826	0	2	2	2	2	2	2	2060352.432	930152.5918
827	0	1	1	1	1	1	1	2069145.551	930283.3303
828	0	1	1	1	1	1	1	2076633.498	939029.5496
829	0	2	2	2	2	2	2	2031500.705	927414.4313
830	0	2	2	2	2	2	2	2050722.169	887987.8045
831	0	2	2	2	2	2	2	2063501.568	912957.6751
832	0	2	2	2	2	2	2	2045377.156	893065.3612
833	0	2	2	2	2	2	2	2056647.052	880468.1068
834	0	1	1	1	1	1	1	2106656.529	933590.1254
835	0	2	2	2	1	2	2	2049807.206	928281.9922
836	0	2	1	1	2	1	1	2084169.485	907471.9545
837	0	1	2	1	1	2	1	2059024.932	941732.6817
838	0	2	2	2	2	2	2	2071250.022	922714.0077
839	0	2	2	2	2	2	2	2078067.374	915216.6917
840	0	1	1	1	1	1	1	2067317.573	885230.6762
841	0	1	2	2	1	2	2	2131852.115	928459.7644
842	0	1	1	2	1	1	2	2053923.854	937310.6497
843	0	2	2	2	2	2	2	2045240.1	939758.4795
844	0	1	1	1	1	1	1	2106601.858	935646.2369
845	0	1	1	1	2	1	1	2111925.763	931904.1962
846	0	2	1	1	2	1	1	2051998.57	867602.113
847	0	1	1	1	1	1	1	2079593.212	901253.4463
848	0	2	2	2	2	2	2	2048098.38	920802.8907
849	0	2	2	2	2	2	1	2054276.395	892249.1564
850	0	1	1	1	1	1	1	2082677.929	907798.8343
851	0	1	1	1	1	1	1	2086611.186	914285.1642
852	0	1	1	1	1	1	1	2036919.798	928617.4018
853	0	1	1	1	1	1	1	2062693.077	931364.5126
854	0	2	2	2	2	2	2	2053906.473	915614.3402
855	0	1	1	1	1	1	1	2053575.526	873544.7915
856	0	2	2	2	2	2	2	2048036.547	916614.8275
857	0	1	1	1	1	2	1	2109923.415	929362.9169
858	0	2	2	2	2	2	2	2081479.367	907068.9028
859	0	1	2	2	1	2	2	2050531.46	902113.2741
860	0	1	1	1	1	1	1	2080162.151	922869.0911

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y	FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y	FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
861	0	1	2	1	1	1	1	2067538.09	932854.748	902	0	1	1	1	1	1	1	2019291.51	945253.619	943	0	1	1	1	1	1	1	2056432.007	949128.6406
862	0	1	1	2	1	1	2	2116556.97	935045.203	903	0	2	2	2	2	2	2	2066304.93	889566.667	944	0	1	1	1	2	1	1	2031226.915	937290.2125
863	0	1	1	1	1	1	2	2115216.64	932303.696	904	0	1	1	1	1	1	1	2079859.5	916405.581	945	0	2	2	2	2	2	1	2113202.02	935388.2697
864	0	1	1	1	1	2	1	2073920.69	915613.578	905	0	1	1	1	1	1	1	2109319.86	934969.416	946	0	1	1	1	1	1	1	2071526.56	912664.4383
865	0	1	1	1	1	1	1	2078108.17	896930.996	906	0	1	1	1	1	1	1	2084307.28	918957.965	947	0	2	2	2	2	2	2	2089533.087	918980.586
866	0	2	2	2	2	2	2	2050759.78	875796.245	907	0	2	2	2	2	2	2	2064087.48	883090.323	948	0	2	2	2	1	1	1	2085146.441	909190.4126
867	0	2	2	2	2	2	2	2046622.04	890063.842	908	0	1	2	1	1	2	1	2066497.81	898648.548	949	0	1	1	1	1	1	1	2139614.757	932294.8684
868	0	1	1	1	1	1	1	2050163.8	949049.633	909	0	1	1	1	1	1	1	2071904.12	933576.894	950	0	1	1	2	1	1	2	2040679.726	919956.7009
869	0	1	1	1	2	1	1	2064735.64	884697.222	910	0	1	1	1	1	1	1	2065255.38	921843.767	951	0	2	2	2	2	2	2	2082018.237	912123.3618
870	0	1	1	1	1	1	1	2066441.67	912664.893	911	0	2	2	2	2	2	1	2048292.34	922489.9	952	0	1	2	1	1	2	1	2041878.042	914319.119
871	0	1	2	1	2	2	1	2079350.66	901892.073	912	0	2	2	2	2	2	2	2065196.6	937398.653	953	0	2	2	2	2	2	1	2045283.593	914227.4289
872	0	1	2	2	1	2	2	2131515.45	922961.413	913	0	2	2	2	2	2	2	2052560.78	910223.708	954	0	1	1	1	1	1	1	2064865.309	890698.7562
873	0	2	1	1	2	1	1	2080966.65	914023.115	914	0	2	2	2	1	2	2	2044341.43	912985.971	955	0	2	1	1	1	1	1	2117313.658	927729.1809
874	0	1	1	1	1	2	2	2033775.29	932823.93	915	0	2	2	2	2	2	2	2057596.72	901889.295	956	0	1	1	1	1	1	1	2091136.557	937692.4845
875	0	2	2	1	2	2	1	2054004.5	902998.449	916	0	2	2	2	1	1	2	2039091.74	931670.139	957	0	2	2	2	2	2	2	2057823.129	930380.4176
876	0	1	1	1	1	1	1	2097574.04	929349.919	917	0	1	1	1	1	1	1	2115096.96	936344.33	958	0	1	1	1	1	1	1	2055490.699	937869.0468
877	0	1	1	1	1	1	1	2095430.04	923249.151	918	0	2	2	2	2	2	2	2069612.53	882876.424	959	0	1	2	1	1	2	1	2055124.924	891681.6135
878	0	2	2	2	2	2	2	2068233.85	931212.999	919	0	1	1	1	2	1	1	2076951.37	905497.712	960	0	1	1	1	1	1	1	2116839.899	935611.487
879	0	1	1	1	1	1	1	2136132.36	923813.169	920	0	1	1	1	2	1	1	2048819.35	869094.332	961	0	1	2	2	1	2	2	2065423.119	915131.2053
880	0	2	2	2	2	2	2	2062141.69	924674.59	921	0	1	1	1	1	1	1	2080384.74	916537.094	962	0	1	1	1	1	1	1	2053557.194	897765.928
881	0	2	2	2	2	2	2	2044269.84	890861.848	922	0	1	1	1	1	1	1	2076380.49	938038.368	963	0	2	2	1	2	2	1	2063261.904	922962.8158
882	0	1	1	2	1	1	2	2130424.45	936310.12	923	0	1	1	1	2	1	1	2040806.12	924101.651	964	0	2	2	2	2	2	2	2042972.431	897855.077
883	0	1	1	1	1	1	1	2055815.3	935181.024	924	0	1	1	1	1	1	1	2067565.6	913266.113	965	0	1	1	1	1	1	1	2048501.357	879349.0153
884	0	1	1	1	1	2	1	2030269.48	939076.04	925	0	2	2	2	2	2	2	2077636.11	915623.893	966	0	1	1	1	1	1	2	2028316.429	932580.5597
885	0	2	2	2	2	2	2	2094515.54	928939.493	926	0	2	2	2	2	2	2	2058706.72	899411.58	967	0	1	1	1	1	1	1	2035646.426	928357.9794
886	0	2	2	2	2	2	2	2065332.1	918150.62	927	0	1	1	1	1	1	2	2066544.56	899331.131	968	0	2	2	2	2	2	2	2035353.277	944809.057
887	0	2	2	2	2	2	2	2050075.97	907383.175	928	0	1	1	1	1	1	1	2046779.17	948347.725	969	0	1	2	1	1	2	1	2086545.788	934047.3981
888	0	2	2	2	2	2	2	2075071.97	903556.776	929	0	1	1	1	1	1	1	2100637.05	940201.39	970	0	2	2	2	2	2	2	2079408.352	909971.1178
889	0	1	1	1	1	1	1	2037087.16	931520.441	930	0	1	1	1	1	1	1	2043134.36	943120.562	971	0	2	2	2	2	2	2	2069830.682	895995.4773
890	0	1	1	1	1	1	1	2052562.52	889317.482	931	0	1	2	2	2	2	2	2053704.18	929819.517	972	0	2	2	2	2	2	2	2064513.84	885819.9837
891	0	1	1	1	1	1	1	2044299.2	946247.534	932	0	1	1	1	1	1	1	2042519.91	926038.792	973	0	2	2	2	2	2	2	2061283.165	896172.7154
892	0	1	2	2	1	2	2	2056192.95	905561.341	933	0	2	2	2	2	2	2	2050521.54	893478.607	974	0	2	2	2	2	2	2	2069326.297	907056.1091
893	0	1	1	1	1	1	1	2100284.81	931425.01	934	0	2	2	2	2	2	2	2059122.43	928850.46	975	0	1	1	1	1	1	1	2054342.714	875507.8919
894	0	2	2	2	2	1	2	2029708.18	941921.185	935	0	1	1	1	1	1	1	2055210.91	934187.643	976	0	2	2	2	2	2	2	2066214.835	886244.8156
895	0	1	2	2	1	2	2	2063999.24	941918.389	936	0	1	1	1	1	1	1	2070422.45	914696.13	977	0	1	1	1	1	1	1	2019173.139	947749.1504
896	0	2	2	2	2	2	2	2078882.3	923417.543	937	0	1	1	1	1	1	1	2031890.66	937472.433	978	0	2	2	2	2	2	2	2075596.799	902160.67
897	0	2	2	2	2	2	2	2054872.03	920745.11	938	0	1	2	2	1	2	2	2088168.23	920847.861	979	0	2	2	2	2	2	2	2053245.178	922823.9941
898	0	1	1	1	1	1	1	2042565.35	947455.136	939	0	1	1	1	1	1	1	2068192.79	905354.794	980	0	1	1	1	2	1	1	2101755.924	936784.6852
899	0	1	1	1	1	1	1	2105962.88	939329.308	940	0	1	1	1	1	1	1	2099581.52	931996.758	981	0	2	2	2	2	2	2	2081433.876	931951.1303
900	0	1	2	2	1	2	2	2063866.12	924760.604	941	0	1	1	1	1	1	1	2053955.48	946952.114	982	0	2	2	2	2	2	2	2048318.677	909650.709
901	0	2	2	2	2	2	2	2067706.17	898167.839	942	0	2	2	2	2	2	1	2044172.46	938184.332	983	0	2	2	2	2	1	2	2052221.571	931530.4979

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y	FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y	FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
984	0	1	1	1	1	1	1	2027478.24	946100.392	1025	0	1	1	1	2	1	1	2046965.22	944243.68	1066	0	2	2	2	2	2	2	2048160.963	907976.787
985	0	1	2	1	1	2	2	2086976.72	938705.038	1026	0	1	1	1	1	1	1	2110982.8	936471.053	1067	0	1	1	1	1	1	1	2050419.994	937059.894
986	0	1	1	1	1	1	1	2057277.4	944393.327	1027	0	1	1	1	1	1	1	2120073.03	936012.566	1068	0	1	1	1	1	1	1	2085352.075	938071.8685
987	0	2	2	1	2	1	1	2125259	939320.554	1028	0	2	2	2	2	2	2	2044373.19	916414.409	1069	0	2	1	2	1	1	2	2062098.243	915480.4851
988	0	1	1	2	1	1	2	2065646.02	919654.902	1029	0	1	2	1	1	1	1	2062022.02	886732.537	1070	0	2	2	2	2	1	2	2063338.165	923915.5077
989	0	1	1	1	2	1	1	2092261.05	940187.53	1030	0	1	1	1	1	1	1	2044996.47	933286.687	1071	0	1	1	1	1	1	1	2098281.862	933106.2869
990	0	1	1	1	1	1	1	2053412.53	939149.258	1031	0	2	2	2	1	2	2	2069434.48	924792.246	1072	0	1	1	1	2	1	1	2052516.143	889724.482
991	0	1	1	1	2	1	1	2138729.75	927981.512	1032	0	2	2	2	2	2	2	2047990.54	925893.999	1073	0	2	2	2	1	2	1	2040384.629	929731.5356
992	0	2	2	2	2	2	2	2076782.01	934800.586	1033	0	1	2	1	1	2	1	2058537.6	906304.711	1074	0	1	1	1	1	1	1	2073269.043	934403.2431
993	0	2	2	2	1	2	2	2060817.34	913859.381	1034	0	1	1	1	1	1	1	2047822.67	941272.953	1075	0	2	2	2	2	2	2	2068502.149	925175.0074
994	0	1	2	1	1	2	1	2073687.31	916519.119	1035	0	1	1	1	1	1	1	2044407.9	946273.288	1076	0	1	1	1	1	1	1	2022605.956	941484.2354
995	0	2	2	2	2	2	2	2070916.61	923872.169	1036	0	1	1	1	1	1	1	2042568.95	948025.307	1077	0	2	2	2	2	2	2	2049347.961	934445.9954
996	0	2	2	2	2	2	1	2049817.75	929002.33	1037	0	1	1	1	1	1	1	2041360.36	932355.405	1078	0	1	1	1	1	1	1	2132811.018	932394.2731
997	0	2	1	1	1	1	1	2072184.89	912167.109	1038	0	1	1	1	1	1	1	2061710.36	910431.911	1079	0	1	1	1	1	1	1	2049591.287	871966.6037
998	0	2	2	2	2	2	2	2055224.61	930164.202	1039	0	2	2	1	2	2	1	2067196.45	933778.212	1080	0	1	1	1	1	1	1	2054928.709	904985.0512
999	0	1	1	1	1	1	1	2130858.02	926184.937	1040	0	1	2	1	1	2	1	2058890.47	918865.522	1081	0	2	2	2	2	2	2	2045027.849	902654.6116
1000	0	1	1	1	1	1	1	2077186.97	905318.66	1041	0	2	2	2	2	1	2	2071063.07	908368.492	1082	0	2	2	2	2	2	2	2044470.269	894089.1888
1001	0	2	2	1	2	2	1	2048259.35	941811.396	1042	0	2	2	2	2	2	2	2057099.27	883045.56	1083	0	2	2	2	1	2	2	2064077.004	901974.862
1002	0	1	1	1	1	1	1	2102790.39	928532.405	1043	0	1	1	1	1	1	1	2034874.16	925956.388	1084	0	2	2	2	1	2	2	2065717.981	891738.1864
1003	0	2	2	2	2	2	2	2051153.7	897465.207	1044	0	1	2	1	2	2	2	2061071.78	923722.37	1085	0	1	2	1	1	2	1	2063167.588	943322.6804
1004	0	2	2	2	2	2	2	2050833.28	874861.542	1045	0	1	1	1	1	1	1	2071379.99	923815.024	1086	0	1	2	2	1	2	2	2058728.006	932603.6011
1005	0	1	1	1	2	1	1	2078265.78	907442.512	1046	0	2	2	2	2	2	2	2054397	886959.24	1087	0	2	2	2	2	2	2	2049103.427	918013.3905
1006	0	2	2	2	2	2	2	2062873.61	883092.588	1047	0	1	1	1	1	1	1	2057040.15	931803.582	1088	0	2	1	1	2	1	1	2100938.609	927580.1203
1007	0	2	2	2	2	2	2	2056769.91	908894.498	1048	0	1	1	1	1	1	1	2032712.06	941313.002	1089	0	1	1	1	1	2	1	2055575.704	891256.5402
1008	0	2	2	1	2	2	2	2047422.33	933085.914	1049	0	1	1	1	2	1	1	2104623.16	927455.705	1090	0	1	2	1	1	2	1	2062367.338	929273.3062
1009	0	1	1	1	1	1	1	2026773.73	938582.477	1050	0	1	2	2	1	2	2	2058467.15	922583.702	1091	0	1	2	2	1	2	2	2069645.764	885191.4619
1010	0	1	1	1	2	1	1	2046253.78	938451.127	1051	0	1	1	1	1	1	1	2071901.08	914096.544	1092	0	1	1	1	1	1	1	2033162.515	927345.823
1011	0	2	2	2	2	2	2	2057135.1	892177.001	1052	0	1	1	1	1	1	1	2071819.93	915112.043	1093	0	2	2	2	2	2	2	2068839.402	912642.3928
1012	0	2	2	2	2	2	2	2054006.54	925115.713	1053	0	1	1	1	1	1	1	2071038.87	930141.308	1094	0	1	1	2	1	1	2	2062388.545	905518.3811
1013	0	2	2	1	2	2	1	2051915.77	896906.156	1054	0	2	2	2	2	2	2	2059966.1	913687.168	1095	0	1	1	1	2	1	1	2106689.033	928702.024
1014	0	1	2	2	2	2	2	2068643.05	933078.928	1055	0	1	1	1	1	1	1	2051568.89	892220.85	1096	0	1	1	1	1	1	1	2055090.118	898433.5315
1015	0	2	2	2	2	2	1	2065049.95	893500.909	1056	0	2	2	2	2	2	2	2073710.58	927727.275	1097	0	1	1	1	1	1	1	2086511.813	932234.4686
1016	0	1	1	1	1	1	1	2035603.43	941362.866	1057	0	2	1	1	2	1	1	2051342.48	885561.797	1098	0	2	2	2	2	2	2	2056462.547	915454.104
1017	0	1	2	1	1	2	2	2058903.35	893895.134	1058	0	2	2	2	1	2	2	2103616.15	931848.219	1099	0	2	2	2	2	2	2	2063158.207	919396.3457
1018	0	1	1	1	1	2	1	2079459.53	897424.772	1059	0	1	1	1	1	1	1	2027195.69	941734.18	1100	0	1	1	2	2	1	2	2057630.277	939368.3146
1019	0	2	2	2	2	2	2	2046284.75	906261.402	1060	0	2	2	2	2	2	2	2056695.46	931024.693	1101	0	2	1	1	2	2	1	2045168.216	930688.1145
1020	0	1	1	1	1	1	1	2062156.83	934321.578	1061	0	2	2	2	2	1	2	2062734.87	901564.417	1102	0	2	2	1	2	2	2	2062313.141	886185.5727
1021	0	1	1	1	1	1	1	2087462.8	923351.183	1062	0	1	1	1	1	1	1	2024561.74	948203.097	1103	0	1	1	1	1	1	1	2089136.757	932445.5211
1022	0	2	2	1	2	2	1	2123676.51	935936.872	1063	0	1	1	1	1	1	1	2030846.76	932381.514	1104	0	2	1	2	2	1	2	2123130.24	933429.4906
1023	0	1	1	1	1	1	1	2064664.21	937453.033	1064	0	1	1	1	2	1	1	2039049.62	936992.972	1105	0	1	1	1	1	2	1	2064302.98	895316.4544
1024	0	1	1	1	1	1	1	2111429.91	939588.2	1065	0	2	2	2	2	2	2	2072505.51	905597.913	1106	0	2	1	1	2	1	1	2075046.604	895124.9006

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
1107	0	2	2	2	2	2	2	2050386.85	888994.609
1108	0	1	1	1	1	1	1	2051621.57	925961.177
1109	0	1	1	1	1	1	1	2139465.1	927456.772
1110	0	1	1	2	1	1	2	2120478.18	938736.522
1111	0	2	2	2	2	2	2	2074875.99	918124.871
1112	0	2	1	1	2	1	2	2050336.04	875785.649
1113	0	1	1	1	1	1	1	2052381.9	949106.927
1114	0	1	2	2	1	2	2	2041665.17	928080.371
1115	0	1	1	1	1	1	1	2068434.61	889778.024
1116	0	2	2	2	2	1	2	2046287.13	905711.207
1117	0	2	2	2	2	2	2	2051889.26	930650.792
1118	0	2	2	2	1	1	2	2065122.23	896513.733
1119	0	1	2	2	1	2	2	2060018.97	902866.027
1120	0	2	2	2	2	2	2	2055598.2	907356.378
1121	0	1	2	1	1	2	1	2107896.51	927288.576
1122	0	1	1	2	1	1	2	2061521.05	909684.669
1123	0	2	2	2	2	2	2	2048182.66	879680.179
1124	0	1	1	1	1	1	1	2089026.35	937068.374
1125	0	2	2	2	2	2	2	2048882.03	870395.702
1126	0	2	2	2	2	2	2	2087292.32	927777.506
1127	0	1	1	1	1	1	1	2056230.61	889236.627
1128	0	1	1	1	1	2	1	2074842.32	918038.243
1129	0	1	2	2	1	2	2	2068836.45	932477.059
1130	0	2	2	2	2	2	2	2057615.07	912886.486
1131	0	1	1	1	1	1	1	2065430.75	920326.602
1132	0	1	1	1	1	1	1	2071946.87	909521.53
1133	0	2	2	2	2	2	2	2044323.51	894547.529
1134	0	1	1	1	2	1	1	2099989.42	929264.87
1135	0	1	1	1	1	1	1	2064355.85	905374.716
1136	0	2	2	2	2	2	2	2055264.47	935983.9
1137	0	1	1	1	1	1	1	2071297.09	885738.976
1138	0	2	2	2	2	2	2	2062981.36	889838.508
1139	0	2	2	1	2	2	1	2063695.04	911358.503
1140	0	2	2	2	2	2	2	2074436.81	907619.44
1141	0	2	2	2	2	2	2	2081101.15	919280.363
1142	0	2	2	2	2	2	2	2057973.95	879831.643
1143	0	1	1	1	1	1	1	2095916.33	927080.737
1144	0	1	1	1	1	1	1	2063674.88	910114.192
1145	0	2	2	2	2	2	2	2055528.8	919681.919
1146	0	1	1	1	1	1	1	2089476.71	939527.266
1147	0	1	1	1	1	1	1	2119516	932277.13

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
1148	0	2	2	2	2	2	2	2081782.24	929327.243
1149	0	1	1	1	1	1	1	2091061.58	930868.407
1150	0	2	2	2	2	2	2	2053811.78	925357.713
1151	0	1	1	1	1	2	2	2118863.95	930471.897
1152	0	2	2	2	2	2	2	2046416.27	913041.934
1153	0	2	2	2	2	2	2	2052879.41	932522.543
1154	0	2	2	2	2	2	2	2063257.53	896949.963
1155	0	2	2	2	2	2	2	2047987.36	866293.449
1156	0	2	2	1	2	2	1	2066145.05	921781.894
1157	0	1	1	1	1	1	1	2060741.99	904551.058
1158	0	2	2	2	2	2	2	2059786.74	895376.175
1159	0	1	1	1	1	1	1	2078451.3	939605.273
1160	0	2	2	2	2	2	2	2064368.64	924178.12
1161	0	2	2	2	2	2	2	2041020.52	895507.08
1162	0	1	1	1	1	1	1	2079429.1	936438.135
1163	0	2	2	2	2	2	2	2071876.94	900407.19
1164	0	1	1	1	2	1	1	2105069.64	928774.882
1165	0	1	1	1	1	1	1	2063819.07	900130.548
1166	0	2	2	2	2	2	2	2068460.25	913339.66
1167	0	1	1	1	1	1	2	2051924.48	881269.974
1168	0	2	2	2	2	2	1	2068083.96	885294.992
1169	0	1	1	1	1	1	1	2067983.63	922298.978
1170	0	1	1	2	2	1	2	2128525.19	936665.728
1171	0	2	2	2	2	2	2	2087951.35	925526.093
1172	0	1	1	1	1	1	1	2036415.59	936805.272
1173	0	1	1	1	1	1	1	2054771.08	935359.789
1174	0	1	1	1	1	1	1	2131410.92	925670.894
1175	0	1	1	1	1	1	1	2059950.77	896936.006
1176	0	1	1	1	1	1	1	2116562.23	936608.546
1177	0	2	2	2	1	2	2	2065346.98	904796.593
1178	0	1	1	1	1	1	1	2089822.78	937728.325
1179	0	2	2	2	2	2	2	2038900.35	932761.542
1180	0	2	2	2	2	2	2	2075711.14	916950.587
1181	0	1	1	1	1	1	1	2021774.07	943074.518
1182	0	1	1	1	2	1	1	2082442.65	927443.363
1183	0	1	1	1	1	1	1	2052177.62	944921.366
1184	0	2	2	2	2	2	2	2088871.32	932640.639
1185	0	1	1	1	1	2	1	2041754.65	934336.887
1186	0	1	1	1	1	1	1	2064250.39	888577.115
1187	0	1	1	2	1	1	2	2066838.57	942925.309
1188	0	1	1	1	2	1	1	2112804.94	939947.355

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
1189	0	1	1	1	1	1	1	2034012.302	932904.6029
1190	0	1	1	1	1	1	2	2064484.525	876245.7323
1191	0	2	2	2	1	2	2	2046106.629	903638.7395
1192	0	2	2	2	2	2	2	2061471.769	938561.1492
1193	0	2	2	2	2	2	2	2067545.251	934740.3052
1194	0	1	1	1	1	1	1	2134217.21	925187.6719
1195	0	2	2	2	2	2	2	2080163.184	929858.7418
1196	0	2	2	2	2	2	2	2042730.034	908886.052
1197	0	1	1	1	1	1	1	2053549.643	884248.856
1198	0	2	2	2	2	2	2	2056104.332	881359.5266
1199	0	2	2	2	2	2	2	2068200.489	920735.0553
1200	0	2	1	2	2	2	2	2123840.387	931100.8895
1201	0	1	1	1	1	1	1	2120130.71	934091.6293
1202	0	1	1	1	1	1	1	2089147.514	935261.9395
1203	0	1	1	1	1	1	1	2060902.831	879806.9157
1204	0	1	1	1	1	1	1	2124528.664	925455.2412
1205	0	2	2	2	2	2	2	2055845.745	880968.0787
1206	0	2	1	2	2	1	2	2044884.273	904550.0533
1207	0	2	2	2	2	2	2	2080621.621	908990.4315
1208	0	1	1	1	1	1	1	2054069.402	884109.2221
1209	0	2	2	2	2	2	2	2048918.471	873481.4464
1210	0	1	1	1	1	1	1	2096237.094	927211.2209
1211	0	1	1	1	1	1	1	2084682.676	926350.52
1212	0	2	1	1	1	2	2	2054913.814	897515.7682
1213	0	2	1	1	2	1	1	2070699.4	902303.4388
1214	0	2	2	1	2	1	1	2086828.184	916333.8812
1215	0	1	1	1	1	1	2	2094326.288	933852.4803
1216	0	1	1	1	1	1	1	2048824.398	893104.058
1217	0	1	1	1	1	1	1	2127903.104	924977.1399
1218	0	1	1	1	1	1	1	2120280.262	937498.8691
1219	0	2	2	2	2	2	2	2052320.91	874210.7026
1220	0	2	2	2	1	2	2	2048291.967	877963.8305
1221	0	1	1	1	1	1	1	2104467.642	928112.8575
1222	0	1	1	1	1	1	1	2127833.457	936427.3986
1223	0	1	2	2	1	2	2	2051221.542	908819.3249
1224	0	2	2	2	2	2	2	2046286.624	895949.292
1225	0	1	1	2	1	1	2	2061047.639	897247.7417
1226	0	1	1	1	1	1	1	2086679.195	920418.2271
1227	0	2	2	2	2	2	2	2060349.293	895933.4761
1228	0	2	2	2	2	2	2	2093449.191	926349.346
1229	0	1	2	1	1	2	2	2064285.704	893925.0653

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y	FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y	FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
1230	0	1	1	1	1	1	1	2130504.49	937032.185	1271	0	2	1	1	2	1	1	2133468.86	937238.231	1312	0	1	1	1	1	1	1	2124411.584	935692.6356
1231	0	1	1	1	2	1	1	2120063.41	937048.109	1272	0	2	2	2	2	2	2	2061453.67	886516.654	1313	0	2	2	2	2	2	2	2058061.721	894230.6343
1232	0	2	2	2	2	2	2	2077776.74	893998.506	1273	0	1	1	1	1	1	1	2086174.47	936902.954	1314	0	1	2	1	1	2	1	2083192.587	928082.8722
1233	0	1	1	1	1	1	1	2081972.29	914096.308	1274	0	2	2	2	2	2	2	2072913.08	903060.839	1315	0	1	1	1	1	1	1	2084947.858	904895.5491
1234	0	1	1	1	2	1	1	2047870.98	898478.202	1275	0	1	1	1	1	1	1	2138265.85	925794.077	1316	0	2	2	2	2	2	2	2063684.995	890705.4963
1235	0	2	2	1	2	1	1	2087104.31	918437.11	1276	0	1	1	1	1	1	1	2120161.1	935933.861	1317	0	1	1	1	1	1	1	2097222.963	930726.5672
1236	0	2	2	2	2	2	2	2044840.94	866921.937	1277	0	1	2	2	1	2	1	2047205.28	907851.331	1318	0	2	2	2	2	2	2	2087834.876	920950.0617
1237	0	1	1	1	1	1	2	2053691.21	909166.115	1278	0	1	1	1	1	1	1	2106792.52	933697.422	1319	0	1	1	1	1	1	1	2084604.065	929723.1215
1238	0	1	1	1	1	1	1	2090661.89	934587.014	1279	0	1	1	1	1	1	1	2119421.36	934058.327	1320	0	1	1	1	2	2	2	2076528.742	905193.8463
1239	0	2	1	1	1	1	1	2119682.01	930452.787	1280	0	2	2	2	2	2	2	2043365.38	908047.877	1321	0	1	1	1	1	1	1	2086870.481	937220.0148
1240	0	2	2	2	2	2	2	2058403.3	902668.677	1281	0	1	1	1	1	1	2	2104444.88	933290.881	1322	0	1	1	1	1	1	1	2119713.566	929994.5845
1241	0	1	1	1	1	2	1	2092790.72	923133.467	1282	0	2	2	2	2	2	2	2070438.99	893657.776	1323	0	1	1	2	1	1	2	2068698.648	890698.2438
1242	0	1	1	1	1	1	1	2051641.06	884325.448	1283	0	1	1	1	1	1	2	2108016.67	936498.003	1324	0	1	1	2	1	1	2	2058191.827	897776.478
1243	0	1	1	1	2	1	1	2092811.84	936025.143	1284	0	1	1	1	1	1	1	2083236.98	906584.96	1325	0	2	2	2	2	2	2	2046107.967	892878.3878
1244	0	2	2	2	2	2	2	2057091.04	878471.264	1285	0	2	2	2	2	2	2	2095949.99	932349.463	1326	0	1	1	1	1	1	1	2054580.325	898555.4234
1245	0	1	1	1	1	1	1	2054441.14	894503.746	1286	0	1	1	1	1	1	1	2086082.33	925835.751	1327	0	1	1	1	1	1	1	2055212.208	884633.1434
1246	0	1	1	1	1	1	1	2073897.2	898970.91	1287	0	2	2	2	2	2	2	2045559.04	897528.623	1328	0	1	1	1	1	1	1	2089490.113	937326.8315
1247	0	1	1	1	1	1	1	2099720.55	933538.19	1288	0	2	2	2	2	2	2	2049756.01	909168.421	1329	0	2	2	2	2	2	2	2050570.316	876337.548
1248	0	1	1	1	1	1	1	2101788.21	937568.377	1289	0	2	2	2	2	2	2	2069449.52	882413.788	1330	0	1	1	1	1	1	1	2049476.023	880341.506
1249	0	1	1	1	1	1	1	2103844.66	937909.452	1290	0	1	1	1	1	1	1	2088152.28	918870.784	1331	0	2	2	2	2	2	2	2079600.984	924644.5659
1250	0	2	2	2	2	2	2	2040925.47	896289.956	1291	0	1	1	1	1	1	1	2092324.84	937285.606	1332	0	2	2	2	2	2	2	2080324.063	919643.1977
1251	0	1	1	1	1	1	1	2069223.54	895082.907	1292	0	2	2	2	2	2	1	2051873.95	879750.067	1333	0	1	1	1	1	1	1	2112552.128	930553.6429
1252	0	2	2	2	2	2	2	2045152.73	898131.398	1293	0	2	2	2	2	2	2	2056282.31	891319.154	1334	0	2	2	2	2	2	2	2072417.873	906453.4623
1253	0	2	2	2	2	2	2	2055338	901528.359	1294	0	1	2	1	1	1	1	2062900.7	899026.609	1335	0	1	1	1	1	1	1	2129012.183	929449.7442
1254	0	2	2	2	2	2	2	2072856.19	897701.731	1295	0	1	1	1	2	1	1	2127016.57	937698.667	1336	0	2	2	2	2	2	2	2061605.537	895211.9925
1255	0	1	1	1	1	1	1	2090034.4	938138.434	1296	0	1	1	1	1	1	2	2080794.91	936490.125	1337	0	1	1	1	2	1	1	2084920.412	922086.0003
1256	0	2	2	2	2	2	2	2042418.05	898792.441	1297	0	1	1	1	1	1	1	2059297.21	895976.194	1338	0	1	1	1	2	2	1	2051983.699	872346.7972
1257	0	2	2	2	2	1	2	2048880.29	873847.895	1298	0	1	1	1	2	1	1	2080292.76	903261.11	1339	0	1	1	1	1	1	1	2108120.953	932261.6513
1258	0	2	2	2	2	2	2	2056057.21	881643.31	1299	0	1	1	2	2	1	2	2123381.91	937234.689	1340	0	1	2	2	1	2	2	2064857.766	888345.8322
1259	0	2	1	1	2	1	1	2127162.46	936285.279	1300	0	1	1	1	2	1	1	2066350.88	907256.33	1341	0	1	1	1	1	1	1	2085211.873	928062.4046
1260	0	2	1	1	1	1	2	2119910.19	929347.784	1301	0	2	2	2	2	2	2	2055877.73	884257.782	1342	0	2	2	2	2	2	2	2077519.144	894740.1944
1261	0	2	2	2	2	2	1	2046523.42	897632.037	1302	0	2	2	2	2	2	2	2073700.66	909523.336	1343	0	1	1	1	1	1	1	2046869.579	892501.6607
1262	0	2	1	1	2	1	1	2087435.95	922580.489	1303	0	2	1	1	2	1	1	2047086.49	901128.26	1344	0	2	2	1	1	1	1	2049371.773	880095.5015
1263	0	1	1	1	1	1	1	2131106.14	925235.099	1304	0	1	1	1	1	1	1	2083736.82	914451.09	1345	0	1	1	1	1	1	1	2128326.253	929712.8707
1264	0	1	1	1	1	2	1	2124896.81	937450.5	1305	0	1	1	1	1	1	1	2084742.39	905116.501	1346	0	1	1	1	1	1	1	2063538.121	909980.685
1265	0	1	1	1	1	1	1	2078859.79	932283.2	1306	0	1	1	1	1	1	1	2107684.95	934449.378	1347	0	2	2	2	1	2	2	2099982.726	938124.4265
1266	0	1	1	1	1	1	1	2078440.2	926377.252	1307	0	2	2	2	2	2	2	2092767.09	932383.357	1348	0	1	1	2	2	1	2	2119553.48	927511.5265
1267	0	1	1	1	1	1	1	2136359.41	932269.669	1308	0	1	2	1	1	2	2	2060891.09	909005.984	1349	0	2	2	2	2	2	2	2083357.976	908316.148
1268	0	2	2	2	2	2	2	2112403.93	931054.848	1309	0	2	1	1	2	1	1	2044993.61	907067.656	1350	0	2	2	2	2	2	2	2063903.447	904158.661
1269	0	2	2	2	2	2	2	2042164.62	892465.685	1310	0	1	1	1	1	1	2	2074472.47	898135.389	1351	0	2	2	1	2	1	2	2047085.13	870603.9436
1270	0	2	2	2	2	2	2	2082646.16	930145.486	1311	0	1	1	1	1	1	1	2111216.26	936922.996	1352	0	2	2	2	2	2	2	2129580.825	936993.0639

FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y	FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y	FID	CID	GT05	GT10	GT15	2005	2010	2015	POINT_X	POINT_Y
1353	0	2	2	2	1	2	2	2098008.787	925587.6808	1402	0	1	1	1	1	1	1	2118188.61	935670.244	1451	0	1	1	1	2	1	1	2136698.393	922703.8731
1354	0	2	2	2	2	2	2	2051678	873173.8947	1403	0	2	2	2	2	2	2	2058863.17	875393.59	1452	0	2	2	2	2	2	2	2111971.134	935220.1392
1355	0	2	2	2	2	2	2	2050755.388	864438.4742	1404	0	2	2	2	2	2	2	2049820.22	909401.185	1453	0	2	2	2	2	1	1	2054760.152	877063.3563
1356	0	1	1	1	2	1	1	2086075.457	917049.5848	1405	0	2	2	2	2	2	2	2071787.41	882912.334	1454	0	1	1	1	2	1	1	2090890.115	938731.0235
1357	0	1	2	1	1	2	1	2058599.489	892904.6744	1406	0	2	2	2	2	2	2	2071739.88	899480.078	1455	0	2	2	2	1	2	2	2071111.031	897754.306
1358	0	2	2	2	2	2	1	2079332.063	916790.326	1407	0	1	1	1	1	1	1	2099539.92	926864.849	1456	0	2	2	2	2	2	2	2057525.267	906479.5429
1359	0	2	2	2	2	2	2	2041254.921	901235.8285	1408	0	2	1	2	2	1	2	2056018.74	907665.588	1457	0	2	2	2	2	2	2	2052203.893	865970.2748
1360	0	2	2	2	2	2	2	2043577.062	897770.1542	1409	0	2	2	2	2	2	2	2135619.95	932025.78	1458	0	2	2	2	2	2	2	2062219.107	877520.1636
1361	0	1	1	1	1	1	1	2128887.58	926087.0717	1410	0	2	2	2	2	2	2	2043490.95	909010.674	1459	0	1	1	1	2	1	1	2110693.831	930351.4427
1362	0	1	1	1	1	1	1	2121716.652	934347.8204	1411	0	1	1	1	1	1	1	2086741.04	905606.823	1460	0	2	2	2	2	2	2	2050779.687	878021.6209
1363	0	2	2	2	2	2	2	2057826.179	883154.7487	1412	0	2	1	2	2	1	2	2060115.45	896164.513	1461	0	1	2	1	1	1	1	2087074.276	918200.9399
1364	0	1	1	1	1	1	1	2084226.174	936553.2046	1413	0	2	2	1	2	2	1	2076013.58	896153.016	1462	0	2	2	1	2	2	1	2131351.268	939586.412
1365	0	1	1	1	1	1	1	2120984.471	934188.6057	1414	0	2	2	2	2	2	2	2045126.88	901738.852	1463	0	1	1	1	1	1	1	2078323.375	930718.0595
1366	0	2	2	2	2	2	2	2119332.805	929017.0207	1415	0	1	1	1	1	1	1	2084117.24	938675.837	1464	0	2	2	2	2	2	2	2046470.276	873257.7894
1367	0	2	2	2	2	2	2	2046318.873	877922.5622	1416	0	1	1	1	1	1	1	2066903.2	884526.785	1465	0	1	1	1	1	1	1	2088561.036	928961.6995
1368	0	1	1	1	1	1	1	2133985.728	930756.8809	1417	0	1	1	1	2	1	1	2116990.49	937910.544	1466	0	1	1	1	2	1	1	2115506.681	938196.4192
1369	0	1	1	1	1	1	1	2079193.543	933169.5418	1418	0	1	1	2	1	1	2	2116978.98	929532.68	1467	0	2	2	2	2	2	2	2041273.104	895519.2486
1370	0	1	1	1	1	1	1	2130986.082	936470.5346	1419	0	2	2	2	2	2	2	2051952.53	908216.452	1468	0	1	1	1	1	1	1	2079325.199	938164.8132
1371	0	2	2	2	2	2	2	2051592.147	896796.8804	1420	0	1	1	2	1	1	2	2053387.35	901484.686	1469	0	1	1	1	1	1	1	2059671.376	883291.3656
1372	0	1	1	1	1	1	2	2109601.897	928663.7541	1421	0	2	2	2	2	2	2	2121575.57	929628.104	1470	0	2	2	2	2	2	2	2045012.289	890272.6159
1373	0	2	2	2	2	2	2	2068659.13	901489.8645	1422	0	2	2	2	2	2	2	2112843.94	931835.635	1471	0	2	2	2	1	2	2	2061278.48	900272.8889
1374	0	1	2	1	1	1	1	2101429.737	934172.2707	1423	0	1	1	1	1	1	1	2058014.11	877060.492	1472	0	2	2	1	2	2	1	2099936.291	938203.4937
1375	0	2	2	2	2	2	2	2080910.617	910296.1905	1424	0	2	2	1	1	2	1	2070860.46	904853.626	1473	0	2	2	2	2	2	2	2064796.792	882872.1474
1376	0	1	1	1	1	1	1	2061742.057	887854.2781	1425	0	1	1	1	1	1	1	2063716.27	902685.047	1474	0	2	2	2	2	2	2	2052868.073	873723.1573
1377	0	1	1	1	1	1	1	2090237.558	936463.0689	1426	0	1	1	1	1	1	1	2112565.51	929717.634	1475	0	1	1	1	1	1	1	2073976.603	904881.1765
1378	0	2	2	2	2	2	2	2070222.576	890525.884	1427	0	1	1	1	1	1	1	2124425.89	935272.824	1476	0	1	2	2	1	2	2	2068024.038	884126.2588
1379	0	1	2	1	1	2	1	2051904.134	876767.5639	1428	0	2	2	2	1	2	2	2064774.91	896159.752	1477	0	1	1	1	1	1	2	2105220.44	933631.4243
1380	0	1	1	1	1	1	1	2090379.022	927445.0817	1429	0	1	1	1	1	1	2	2078347.57	895180.226	1478	0	1	1	1	1	1	1	2053527.788	873307.9282
1381	0	1	1	2	1	1	2	2057717.834	909178.8337	1430	0	2	2	2	2	2	2	2122289.37	937791.516	1479	0	2	2	2	2	1	2	2070114.499	902748.6944
1382	0	2	1	1	2	1	1	2133243.56	934814.3461	1431	0	2	2	2	2	2	2	2043258.49	905679.555	1480	0	1	1	1	1	2	1	2078377.998	901982.123
1383	0	2	2	2	2	1	2	2073990.23	907778.7662	1432	0	1	1	1	2	1	1	2083781.75	917443.953	1481	0	1	2	2	1	2	2	2077340.621	909539.7496
1384	0	2	2	2	2	2	2	2053013.276	889368.6941	1433	0	1	1	1	1	1	1	2106239.63	934178.274	1482	0	2	2	2	2	2	2	2057671.952	902107.7814
1385	0	2	2	2	2	2	2	2045944.097	908528.7354	1434	0	1	1	1	1	1	1	2130082.68	923810.144	1483	0	1	1	1	1	1	1	2087623.681	935048.5923
1386	0	1	1	1	2	1	1	2090890.161	928224.1575	1435	0	1	1	1	1	1	1	2065685.06	889213.953	1484	0	2	2	2	2	2	2	2049793.938	900927.6357
1387	0	1	1	1	1	1	1	2068744.151	894606.1864	1436	0	1	2	1	1	2	1	2058510.43	908096.577	1485	0	1	1	1	1	1	1	2064666.375	885601.0086
1388	0	1	2	1	1	2	1	2088804.176	917047.0626	1437	0	2	2	2	2	2	2	2077774.62	905805.922	1486	0	2	1	2	2	1	1	2087687.019	929935.5751
1389	0	1	2	1	1	2	1	2075308.864	898394.0565	1438	0	2	2	2	2	2	2	2054748.29	880155.787	1487	0	2	2	2	2	2	2	2055083.279	876604.3196
1390	0	2	2	2	2	2	2	2040775.58	909869.0356	1439	0	2	1	2	2	1	2	2065062.71	890338.404	1488	0	1	1	1	1	1	1	2060211.218	898271.103
1391	0	1	2	2	1	2	2	2067328.289	905442.5881	1440	0	1	1	1	1	1	1	2043429.44	867942.925	1489	0	2	2	2	2	2	2	2046735.189	894599.4914
1392	0	2	2	2	2	2	2	2055355.645	889993.197	1441	0	1	1	1	1	1	1	2058718.81	878203.505	1490	0	1	1	1	1	1	1	2042980.84	905836.6658
1393	0	2	1	2	1	1	2	2060641.089	900378.8996	1442	0	2	2	2	2	2	2	2076827.57	900702.818	1491	0	1	1	2	1	1	2	2089681.765	922398.371
1394	0	2	2	2	2	2	2	2065800.31	909042.6228	1443	0	1	1	1	1	1	1	2103374.23	930740.943	1492	0	2	2	2	2	2	2	2050183.067	874566.6215
1395	0	1	1	2	1	1	2	2060020.589	909510.2649	1444	0	2	2	1	1	1	1	2108857.32	936951.001	1493	0	2	2	2	2	2	2	2078603.33	909270.0009
1396	0	2	2	2	2	2	2	2050694.784	882250.0708	1445	0	2	2	2	2	2	2	2060858.82	903172.11	1494	0	1	1	1	2	1	1	2099320.689	939858.2665
1397	0	2	2	2	2	2	2	2058805.229	895616.7092	1446	0	2	2	2	2	2	2	2096129.67	930627.07	1495	0	1	1	1	1	1	1	2139991.466	930172.8601
1398	0	2	2	2	2	2	2	2045795.313	897617.5276	1447	0	2	2	2	2	2	2	2062456.68	875594.94	1496	0	2	2	2	2	1	2	2060867.211	878483.6521
1399	0	2	2	2	1	2	2	2065452.807	906114.5177	1448	0	1	1	1	1	1	1	2041685.11	906372.322	1497	0	2	2	2	2	2	2	2121100.047	932529.8525
1400	0	1	2	1	1	1	1	2090965.723	923615.6242	1449	0	2	2	2	2	2	2	2087632.97	916848.159	1498	0	2	2	2	2	2	2	2067480.383	903656.6385
1401	0	2	2	1	2	2	1	2041427.264	907862.9396	1450	0	2	2	2	2	2	2	2042263.94	904687.53	1499	0	2	1	1	2	1	1	2066659.798	899121.4756

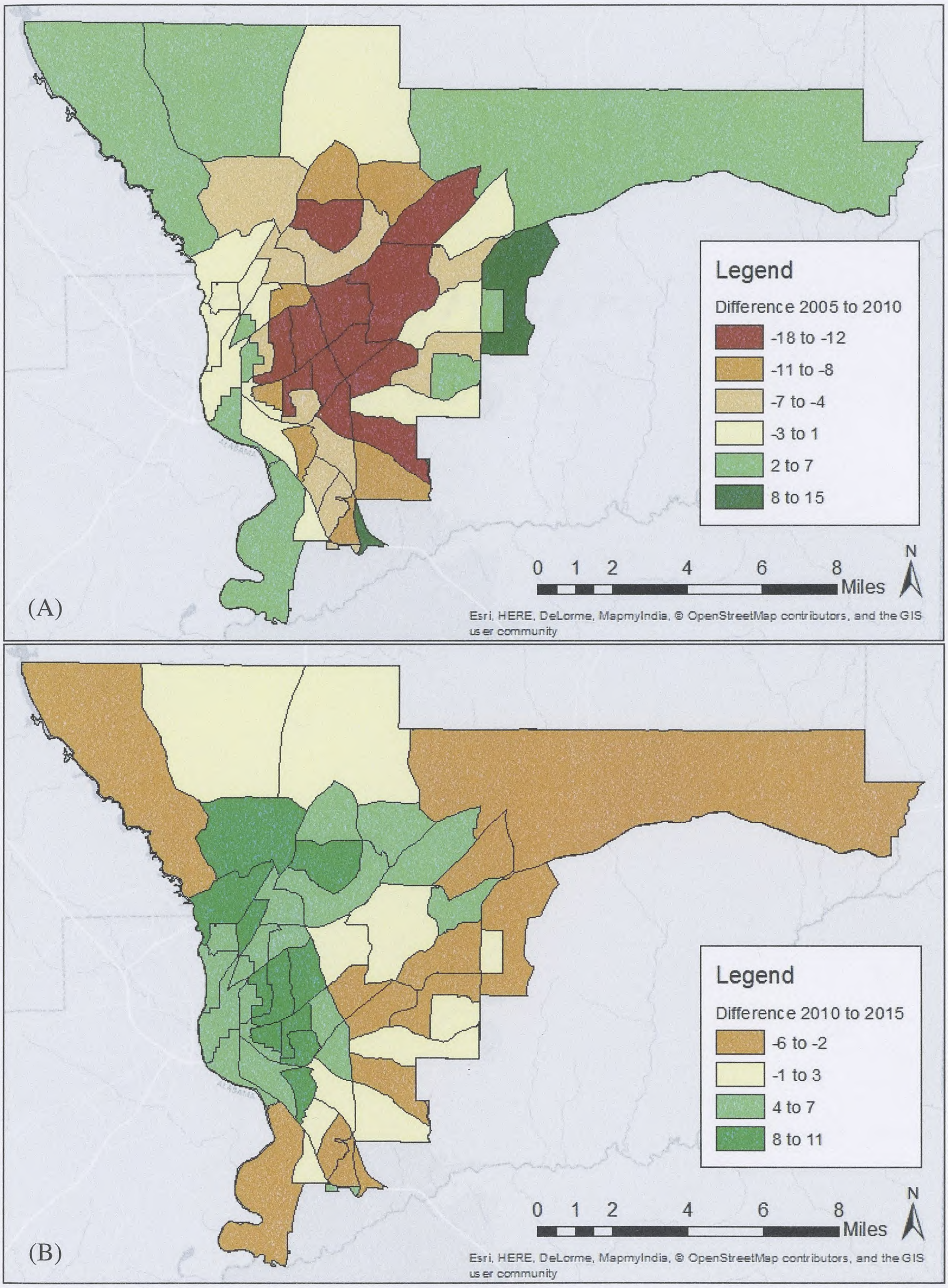

Figure 1. City of Columbus tree canopy change by census tract between: A) 2005 and 2010 and B) 2010 and 2015. Dark green represents canopy gains and light green represents loss in canopy over time.

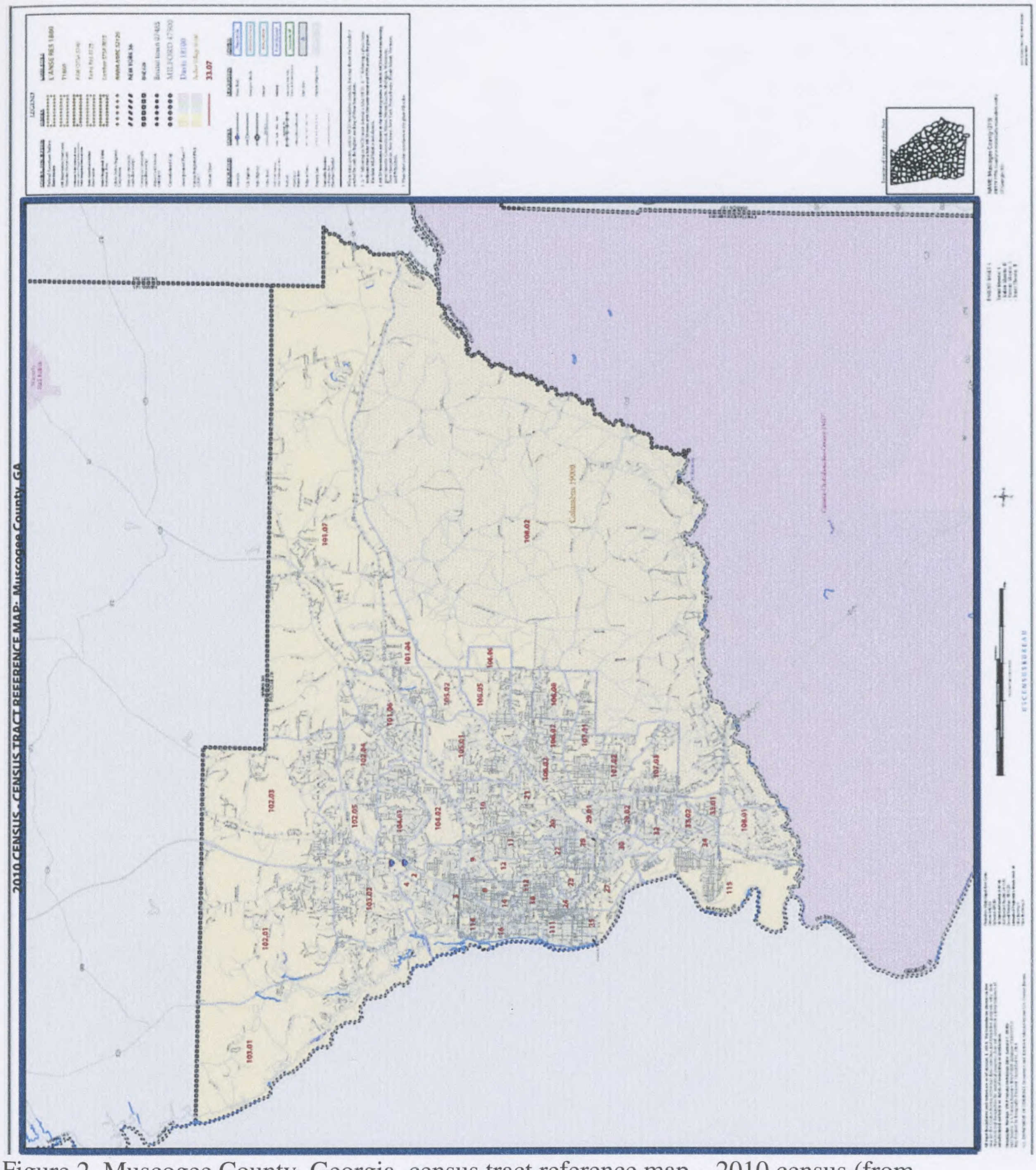

Figure 2. Muscogee County, Georgia, census tract reference map – 2010 census (from census.gov).

Table 5. City of Columbus census tract percent tree canopy detail.

FID	NAME	2005 % Tree	2010 % Tree	2015 % Tree	Difference '05 to '10	Difference '10 to '15	Difference '05 to '15
0	104.01	46	33	41	-13	8	-6
1	101.06	49	37	41	-12	4	-8
2	102.04	43	35	40	-8	5	-3
3	102.05	37	28	32	-9	4	-6
4	102.03	59	57	58	-2	1	-1
5	103.01	63	67	64	4	-3	2
6	102.01	73	75	75	2	0	2
7	101.07	63	70	66	7	-4	2
8	101.04	44	42	40	-2	-2	-5
9	106.06	31	37	37	6	0	6
10	10	50	36	37	-14	1	-13
11	105.01	63	48	49	-15	1	-14
12	104.02	27	21	24	-6	3	-3
13	105.02	49	44	47	-5	3	-2
14	12	56	41	50	-15	9	-6
15	112	38	32	42	-6	10	4
16	14	14	21	27	7	6	13
17	8	35	32	37	-3	5	2
18	114	28	28	34	0	6	6
19	3	21	20	27	-1	7	5
20	9	41	30	34	-11	4	-6
21	111	11	10	13	-1	3	2
22	28	36	30	39	-6	9	3
23	22	49	34	42	-15	8	-8
24	23	43	35	43	-8	8	1
25	18	16	19	24	3	5	8
26	29.01	53	40	44	-13	4	-9
27	107.01	46	43	45	-3	2	-1
28	20	36	23	28	-13	5	-8
29	106.02	52	37	35	-15	-2	-17
30	21	56	43	40	-13	-3	-16
31	11	60	42	49	-18	7	-11
32	33.02	48	44	41	-4	-3	-7
33	32	29	25	27	-4	2	-2
34	107.03	43	32	31	-11	-1	-12
35	29.02	31	24	26	-7	2	-4
36	107.02	52	40	37	-12	-3	-15
37	30	44	36	44	-8	8	0
38	27	24	23	29	-1	6	4
39	25	9	13	18	4	5	9
40	24	16	17	22	1	5	6
41	108.02	56	71	69	15	-2	12
42	106.07	41	36	34	-5	-2	-6
43	106.05	39	36	34	-3	-2	-5
44	106.08	25	31	31	6	0	6
45	108.01	47	41	44	-6	3	-4
46	33.01	59	51	49	-8	-2	-10
47	4	33	30	41	-3	11	9
48	2	27	22	28	-5	6	1
49	103.02	41	36	46	-5	10	5
50	16	22	19	24	-3	5	2
51	115	36	41	35	5	-6	0
52	34	23	23	23	0	0	1

Table 6. City of Columbus census tract air quality benefits.

FID	NAME	Area (ha)	Tree (ha)	Air Pollutant Removal (kg/yr)	CO2seq (kg/yr)	Air Pollutant Removal (kg/ha)	CO2seq (kg/ha)	CO2seq (tonnes/ha)	Population 2010
0	104.01	510	206	17,856	2665516	35.0	5224	5.2	6401
1	101.06	723	293	25,411	3793234	35.2	5249	5.2	5451
2	102.04	585	232	20,088	2998705	34.3	5123	5.1	6013
3	102.05	502	159	13,736	2050397	27.3	4081	4.1	2911
4	102.03	2955	1710	148,172	22118654	50.1	7485	7.5	7933
5	103.01	3502	2249	194,873	29090003	55.7	8307	8.3	2478
6	102.01	3201	2402	208,093	31063509	65.0	9704	9.7	6740
7	101.07	9197	6020	521,607	77863811	56.7	8466	8.5	7265
8	101.04	583	230	19,917	2973075	34.2	5102	5.1	6532
9	106.06	176	65	5,666	845789	32.2	4802	4.8	1834
10	10	492	182	15,796	2357956	32.1	4792	4.8	4384
11	105.01	1054	515	44,640	6663789	42.3	6322	6.3	6399
12	104.02	704	166	14,422	2152916	20.5	3056	3.1	4049
13	105.02	370	176	15,281	2281066	41.3	6159	6.2	1406
14	12	298	149	12,877	1922247	43.2	6454	6.5	3371
15	112	137	57	4,979	743269	36.3	5415	5.4	1942
16	14	83	22	1,889	281930	22.8	3402	3.4	1768
17	8	158	57	4,979	743269	31.5	4705	4.7	2431
18	114	148	50	4,292	640749	29.1	4340	4.3	2132
19	3	163	44	3,777	563859	23.1	3456	3.5	1741
20	9	174	59	5,151	768899	29.7	4431	4.4	2851
21	111	388	52	4,464	666379	11.5	1715	1.7	1992
22	28	171	67	5,838	871419	34.2	5098	5.1	2107
23	22	158	65	5,666	845789	35.9	5353	5.4	2795
24	23	117	52	4,464	666379	38.3	5718	5.7	1785
25	18	111	26	2,232	333189	20.0	2992	3.0	1272
26	29.01	241	107	9,271	1384018	38.5	5746	5.7	2878
27	107.01	627	279	24,209	3613824	38.6	5766	5.8	6010
28	20	215	61	5,323	794529	24.8	3696	3.7	3266
29	106.02	383	135	11,675	1742837	30.5	4547	4.5	4936
30	21	311	125	10,817	1614687	34.8	5195	5.2	2381
31	11	326	161	13,907	2076027	42.6	6362	6.4	2588
32	33.02	223	91	7,898	1178978	35.5	5293	5.3	2455
33	32	197	52	4,464	666379	22.7	3385	3.4	1744
34	107.03	552	170	14,766	2204176	26.8	3995	4.0	5995
35	29.02	306	81	7,039	1050828	23.0	3438	3.4	2249
36	107.02	482	178	15,452	2306696	32.1	4788	4.8	4764
37	30	189	83	7,211	1076458	38.1	5693	5.7	2676
38	27	376	107	9,271	1384018	24.7	3685	3.7	2710
39	25	272	48	4,121	615119	15.2	2262	2.3	2626
40	24	98	22	1,889	281930	19.2	2865	2.9	1581
41	108.02	1150	791	68,506	10226353	59.6	8895	8.9	6454
42	106.07	440	153	13,220	1973507	30.0	4482	4.5	5328
43	106.05	588	202	17,513	2614256	29.8	4447	4.4	4146
44	106.08	347	109	9,443	1409648	27.2	4062	4.1	4156
45	108.01	32	14	1,202	179410	37.7	5631	5.6	1427
46	33.01	150	73	6,353	948308	42.3	6313	6.3	1317
47	4	557	230	19,917	2973075	35.8	5339	5.3	2841
48	2	300	83	7,211	1076458	24.0	3583	3.6	2498
49	103.02	1251	581	50,306	7509578	40.2	6003	6.0	6293
50	16	228	55	4,807	717639	21.1	3149	3.1	2749
51	115	1370	476	41,207	6151190	30.1	4490	4.5	5496
52	34	176	42	3,606	538229	20.5	3056	3.1	2338

APPENDIX B – $PM_{2.5}$ FIELD STUDY SUPPLEMENTAL DATA

Table 7. Sampling locations details used for statistical analysis.

Date	Time	Site Name	Location	Treatment	$PM_{2.5}$ ($\mu g/m^3$) (Median corrected)	Unit	Type	Temp (°C)	% RH	Device less Wind Direction (°)	Wind Speed (mps)	Fort Benning Burn?	City $PM_{2.5}$ ($\mu g/m^3$)	PM Source Level (EPA AQI Based)	Peak $PM_{2.5}$ ($\mu g/m^3$)	Distance to PM Source (m)	Tree density (m)
2/1/2017	16:00	4th Street Park	Loc 1	Tree	2.1	a1	Line	22.4	39.8	38	1.5	Y	1.1	L	2	15	10
2/1/2017	16:00	4th Street Park	Loc 1	Open	1.9	a3	Line	22.4	39.8	38	1.5	Y	1.1	L	2.9	15	10
2/2/2017	17:00	CSU	Loc 1	Tree	13.5	a1	Field	23.4	53.8	39	0.4	N	11.9	L	3.2	40	75
2/2/2017	17:00	CSU	Loc 1	Open	10.9	a3	Field	23.4	53.8	39	0.4	N	11.9	L	1.1	40	75
2/2/2017	17:00	CSU	Loc 2	Tree	13.4	a1	Field	22.8	54.8	12	0.5	N	11.9	L	3.6	40	75
2/2/2017	17:00	CSU	Loc 2	Open	10.8	a3	Field	22.8	54.8	12	0.5	N	11.9	L	1.5	40	75
2/3/2017	16:00	Bike Park E	Loc 1	Tree	9.4	a3	U-Shaped	13.6	67.9	1	2.5	N	8.8	L	2.7	30	20
2/3/2017	16:00	Bike Park E	Loc 1	Open	10	a1	U-Shaped	13.6	67.9	1	2.5	N	8.8	L	3.3	30	20
2/3/2017	16:00	Bike Park E	Loc 2	Tree	10.5	a3	U-Shaped	13	68.8	1	2.1	N	8.8	L	4.6	40	20
2/3/2017	16:00	Bike Park E	Loc 2	Open	13.2	a1	U-Shaped	13	68.8	1	2.1	N	8.8	L	6	40	20
2/3/2017	17:00	Bike Park E	Loc 3	Tree	12.7	a3	U-Shaped	13	68.3	8	3.1	N	5.5	L	9.1	55	20
2/3/2017	17:00	Bike Park E	Loc 3	Open	14.8	a1	U-Shaped	13	68.3	8	3.1	N	5.5	L	10.9	55	20
2/9/2017	16:00	All Sts Church	Loc 1	Tree	2.6	a3	U-Shaped	12.1	38.4	8	5.1	N	2.1	L	3.3	60	65
2/9/2017	16:00	All Sts Church	Loc 1	Open	2.6	a1	U-Shaped	12.1	38.4	8	5.1	N	2.1	L	7.9	60	65
2/9/2017	17:00	All Sts Church	Loc 2	Tree	3.3	a3	U-Shaped	12.3	36.7	0	3.1	N	2.9	L	5.1	85	65
2/9/2017	17:00	All Sts Church	Loc 2	Open	5	a1	U-Shaped	12.3	36.7	0	3.1	N	2.9	L	8.7	85	65
2/10/2017	16:00	Cascade Church E	Loc 1	Tree	1.4	a3	Line	21.3	19.4	136	0.7	N	0.7	L	1.7	45	20
2/10/2017	16:00	Cascade Church E	Loc 1	Open	1.7	a1	Line	21.3	19.4	136	0.7	N	0.7	L	1.9	45	20
2/13/2017	17:00	Bike Park W	Loc 1	Tree	39.8	a2	Field	21.2	22.9	1	2.1	N	8.5	M	37.5	50	50
2/13/2017	17:00	Bike Park W	Loc 1	Open	34.1	a3	Field	21.2	22.9	1	2.1	N	8.5	M	34.6	50	50
2/15/2017	17:00	Cunningham	Loc 1	Tree	2.8	a2	Line	16.4	35.4	0	2.5	N	1	L	4.9	23	15
2/15/2017	17:00	Cunningham	Loc 1	Open	3.1	a3	Line	16.4	35.4	0	2.5	N	1	L	5.1	23	15
2/17/2017	17:00	Corner Uni-Man	Loc 1	Tree	6.3	a3	U-Shaped	20.2	27.4	1	1.2	Y	4.4	L	5.3	135	70
2/17/2017	17:00	Corner Uni-Man	Loc 1	Open	7.5	a2	U-Shaped	20.2	27.4	1	1.2	Y	4.4	L	7	135	70
2/17/2017	17:00	Corner Uni-Man	Loc 2	Tree	9.8	a3	U-Shaped	20.2	26.6	1	2.3	Y	4.4	H	26.1	160	70
2/17/2017	17:00	Corner Uni-Man	Loc 2	Open	18.3	a2	U-Shaped	20.2	26.6	1	2.3	Y	4.4	H	75.5	160	70
2/19/2017	15:00	Haverty's	Loc 1	Tree	6.9	a1	Field	24.9	44.2	278	0.7	N	3.8	L	5.5	45	90
2/19/2017	15:00	Haverty's	Loc 1	Open	6.9	a3	Field	24.9	44.2	278	0.7	N	3.8	L	4.6	45	90
2/19/2017	15:00	Lazyboy	Loc 1	Tree	7	a3	Field	27.2	38.1	0	0.6	N	3.8	L	5.5	15	45
2/19/2017	15:00	Lazyboy	Loc 1	Open	7.2	a2	Field	27.2	38.1	0	0.6	N	3.8	L	6.3	15	45
2/19/2017	15:00	Lazyboy	Loc 2	Tree	5.8	a3	Field	26.5	40.3	23	1.6	N	3.8	L	4.9	20	45
2/19/2017	15:00	Lazyboy	Loc 2	Open	6.7	a2	Field	26.5	40.3	23	1.6	N	3.8	L	4.9	20	45

Date	Time	Site Name	Location	Treatment	$PM_{2.5}$ (µg/m^3) (Median corrected)	Unit	Type	Temp (°C)	% RH	Device less Wind Direction (°)	Wind Speed (mps)	Fort Benning Burn?	City $PM_{2.5}$ (µg/m^3)	PM Source Level (EPA AQI Based)	Peak $PM_{2.5}$ (µg/m^3)	Distance to PM Source (m)	Tree density (m)
2/20/2017	17:00	Colony Bank	Loc 1	Tree	11.3	a1	U-Shaped	24.3	42.4	1	1.5	N	7.2	L	12.4	130	15
2/20/2017	17:00	Colony Bank	Loc 1	Open	10.8	a3	U-Shaped	24.3	42.4	1	1.5	N	7.2	L	10.3	130	15
2/20/2017	17:00	Colony Bank	Loc 2	Tree	10.3	a1	U-Shaped	24.1	43	1	1.8	N	7.2	L	8.3	145	15
2/20/2017	17:00	Colony Bank	Loc 2	Open	11.1	a3	U-Shaped	24.1	43	1	1.8	N	7.2	L	7.8	145	15
2/20/2017	17:00	Colony Bank	Loc 3	Tree	22.1	a1	U-Shaped	23.9	43.8	1	1.9	N	7.2	H	59.6	160	15
2/20/2017	17:00	Colony Bank	Loc 3	Open	21.9	a3	U-Shaped	23.9	43.8	1	1.9	N	7.2	H	73.3	160	15
2/23/2017	8:00	Cascade Church W	Loc 1	Tree	12.9	a2	Line	17.3	85.9	66	1.1	N	4.2	L	12.4	80	28
2/23/2017	8:00	Cascade Church W	Loc 1	Open	12.1	a1	Line	17.3	85.9	66	1.1	N	4.2	L	10.5	80	28
2/23/2017	8:00	Cascade Church W	Loc 2	Tree	12.5	a2	Line	17.4	85.6	66	2.2	N	4.2	L	12.4	90	28
2/23/2017	8:00	Cascade Church W	Loc 2	Open	11.5	a1	Line	17.4	85.6	66	2.2	N	4.2	L	10.4	90	28
2/23/2017	8:00	Cascade Church E	Loc 1	Tree	12.2	a1	Line	17.5	87.1	226	1.8	N	4.2	L	12.1	45	20
2/23/2017	8:00	Cascade Church E	Loc 1	Open	11.8	a2	Line	17.5	87.1	226	1.8	N	4.2	L	10.7	45	20
2/23/2017	16:00	CSU Baseball	Loc 1	Tree	18.1	a1	Line	24.8	49	15	1.3	N	1.8	H	76.7	150	25
2/23/2017	16:00	CSU Baseball	Loc 1	Open	21	a3	Line	24.8	49	15	1.3	N	1.8	H	93.1	150	25
2/23/2017	16:00	CSU Baseball	Loc 2	Tree	8.6	a1	Line	24.7	50.4	5	0.4	N	1.8	L	11.8	170	25
2/23/2017	16:00	CSU Baseball	Loc 2	Open	8.3	a3	Line	24.7	50.4	5	0.4	N	1.8	L	11.9	170	25
2/24/2017	16:00	St. Marys Church	Loc 1	Tree	10.2	a2	Line	28.2	43.1	33	2.4	Y	4.1	L	9.4	55	10
2/24/2017	16:00	St. Marys Church	Loc 1	Open	11	a3	Line	28.2	43.1	33	2.4	Y	4.1	L	11.2	55	10
2/24/2017	16:00	St. Marys Church	Loc 2	Tree	12.6	a2	Line	28.6	39.9	33	1.6	Y	4.1	L	12.1	60	10
2/24/2017	16:00	St. Marys Church	Loc 2	Open	12.3	a3	Line	28.6	39.9	33	1.6	Y	4.1	L	11.2	60	10
2/28/2017	16:00	Williams Rd Lot	Loc 1	Tree	18.1	a2	Field	22.1	74.85	0	1.3	N	9.3	L	16.1	30	60
2/28/2017	16:00	Williams Rd Lot	Loc 1	Open	15.4	a3	Field	22.1	74.85	0	1.3	N	9.3	L	10.2	30	60
2/28/2017	16:00	Williams Rd Lot	Loc 2	Tree	16.7	a2	Field	24.5	70.7	0	0	N	9.3	L	11.9	45	60
2/28/2017	16:00	Williams Rd Lot	Loc 2	Open	15.1	a3	Field	24.5	70.7	0	0	N	9.3	L	9.8	45	60
2/28/2017	16:00	Williams Rd Lot	Loc 1	Tree	16.6	a2	Field	24	68.3	0	0.9	N	9.3	L	12.5	23	60
2/28/2017	16:00	Williams Rd Lot	Loc 1	Open	15.3	a3	Field	24	68.3	0	0.9	N	9.3	L	11.6	23	60
2/28/2017	16:00	Williams Rd Lot	Loc 2	Tree	16.4	a2	Field	25	65.5	0	0	N	9.3	L	11.6	40	60
2/28/2017	16:00	Williams Rd Lot	Loc 2	Open	15.5	a3	Field	25	65.5	0	0	N	9.3	L	10.3	40	60

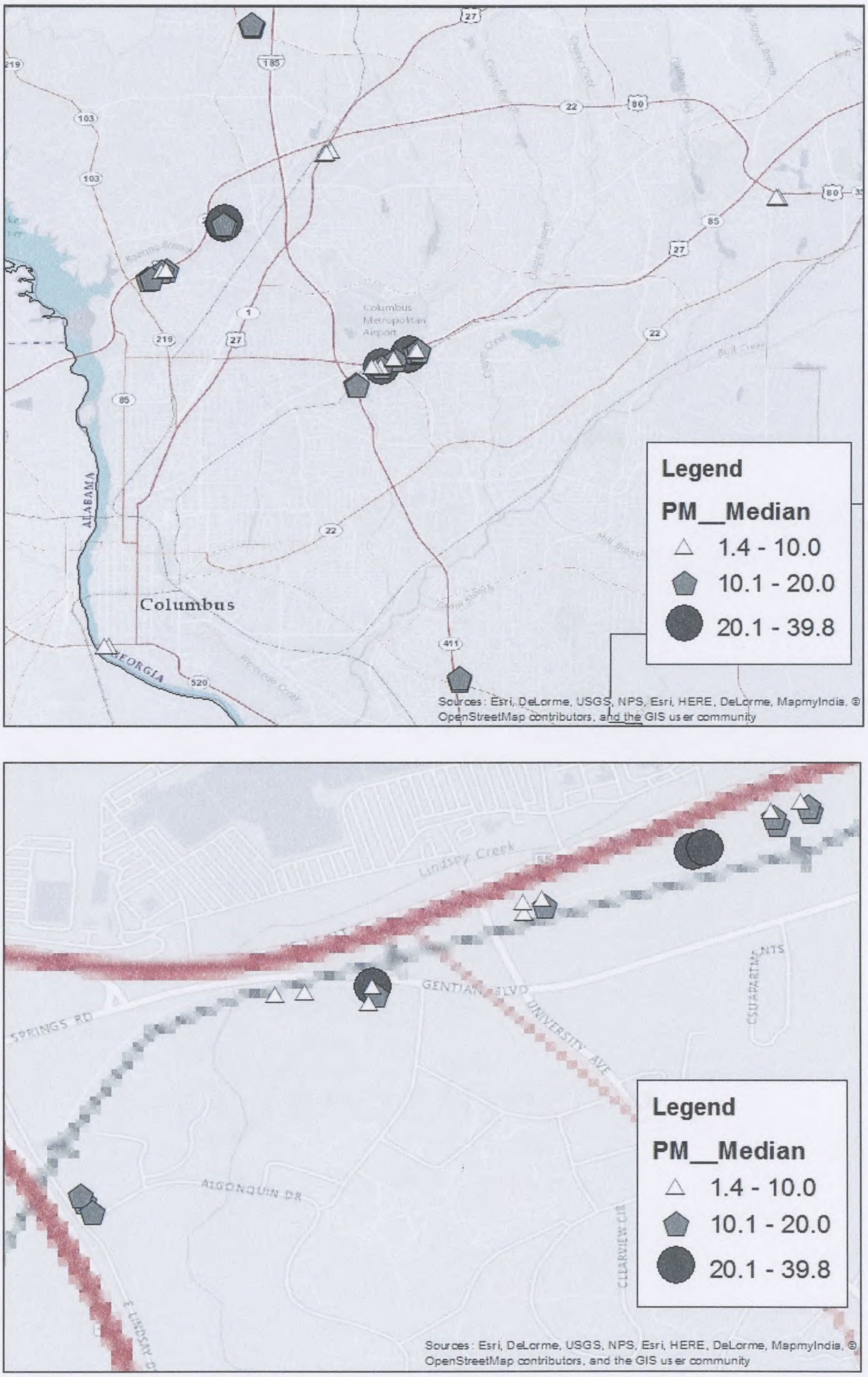

Figure 3. A) Variation in average particulate concentrations by sample location. B) Zoomed view to highlight locations closely clustered.

Field Sites AirBeam Tests Metadata

The following figures and metadata provide details on each study site. Figures highlight test locations, tree and open field, with white markers (numbers indicate which AirBeam unit was used at that place, i.e. #1, 2 or 3). The start and end location, equivalency check, of all AirBeams is represented with a yellow marker.

4th Street River Walk Access Parking Lot 2-1-17

When:	2-1-17 16:00-17:15 EDT
Who:	K. Youngquist and Care Bacon
Where:	4th Street River walk access parking lot
What:	4th street has a thin line of trees near highway 280. Test in tree line compared to open grass near parking lot. Units 1 and 3 used based on equivalency tests.
How:	Unit 1 placed in treeline and unit 3 in field next to parking lot.
Notes:	26 trees bigger than 3 inch diameter and less than 5 inch diamter in line of sight. Road is higher elevation than trees and field.
Hypothesis:	Thin tree line will not create enough of a fence to reduce particulate matter farther from the road as compared with open parking lot without trees.

Particulate Notes

Time	Note
16:25-16:37	2 cars idle in parking lot
16:54-17:01	Smell of smoke. Fort Benning perscribed burn earlier (around noon). Wind shifted from out of SW.

Car Data:

Time	Cars	Minutes	Cars/Min
16:30	45	1	45
16:40	47	1	47
16:45	127	2	63.5
16:56	90	2	45
17:03	101	2	50.5

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
15:00	0.1
16:00	1.1
17:00	1.7
18:00	2.8

Weather

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)
17:15	SW	9	73	36	44	30.10

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Direction (°)	Wind Speed (mph)	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
16:18pm	W	270	4.7	22.8	38.8			29.75	
16:28pm	W	270	3.7	21.7	34.9	7.3	13.8	29.75	
16:33pm	NW	315	6.2	22.2	39.7	7.6	13.7	29.76	140
16:38pm	NW	315	8.1	22.1	41.3	8.2	13.9	29.75	145
16:43pm	NW	315	3.1	22.4	40.5	8.8	14.6	29.76	135
16:49pm	W	270	1.3	22.4	39.6	8.0	14.1	29.76	136
16:51pm			0						
16:53pm			0	22.4	41.0	8.6	14.4	29.75	145
16:54pm	SW	225	4						
16:58pm	NW	315	5.4	22.6	40.8	8.8	14.6	29.74	158
17:03pm	NW	315	1.8	22.7	40.8	9.1	14.9	29.75	145
17:08pm	NW	315	2.9	22.8	40.8	8.4	14.3	29.77	143
Average	WNW	292.5	3.4	22.4	39.8	8.3	14.3	29.75	143

Airbeam Location Data:

Time	Lat A1	Long A1	Lat A3	Long A3	Device Facing Direction (°)	Elevation A1 (ft)	Elevation A3 (ft)	Location
16:07-17:08	32.4529361°	-84.9926944°	32.4529389°	-084.9935917°	330° NW	310	230	1

Figure 5. The River Walk parking lot has a thin tree buffer adjacent to highway 280.

Columbus State University ROTC 2-217

When:	2-2-17 15:30-17:52 EDT
Who:	K. Youngquist and Care Bacon
Where:	CSU Lindsey Creek Road/ROTC Field
What:	CSU has dense line of trees near I-185. Test in tree line compared to open area near sign. Units 1 and 3 used based on equivalency tests.
How:	Unit 1 placed in treeline and unit 3 in open.
Notes:	Road is 10 feet lower elevation than trees and field.
Hypothesis:	In the winter, dense tree line will have higher particulate matter level as compared with open area without trees.

Particulate Notes

Time	Note
17:02	Campus police smoking near bridge. Smelled worse in trees.
17:03	Staff leaving campus
17:42-17:43	ROTC ran by devices and through the trees

Car Data:

Time	Cars	Minutes	Cars/Min
16:57	242	2	121
17:19	254	2	127
17:29	250	2	125
17:38	237	2	119
17:48	282	2	141

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
14:00	7.1
15:00	7.9
16:00	9.7
17:00	11.9
18:00	11.1

Weather

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)
17:00	W	9	73	51	53	30.13

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Direction (°)	Wind Speed (mph)	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
16:56	W	270	0.9	23.9	51.6	13.4	17.3	29.73	166
17:01	W	270	1.0	23.4	55.0	14.0	17.5	29.74	161
17:06	W	270	1.5	23.3	52.6	13.0	16.8	29.73	166
17:11			0	22.9	56.1	13.5	16.9	29.73	165
17:17			0	22.9	55.1	13.5	16.9	29.73	165
17:22			0	22.8	55.7	13.2	16.6	29.73	166
17:26	SW	225	1.3	22.8	54.4	13.1	16.7	29.73	165
17:31			0	24.2	51.7	13.9	17.5	29.73	166
17:36	SW	225	1.4	23.1	53.2	13.3	16.9	29.73	166
17:41	SW	225	1.7	22.6	55.5	13.3	16.7	29.73	165
17:46	W	270	2.7	22.0	56.5	13.0	16.4	29.74	161
17:51	W	270	1.6	21.9	56.4	12.8	16.2	29.74	158

Airbeam Location Data:

Time	Lat A1	Long A1	Lat A3	Long A3	Device Facing Direction (°)	Elevation (ft)	Location
16:48-17:15	32.502139	-84.946553	32.501955	-84.94642	231° SW	314	1
17:16-17:52	32.502222	-84.946608	32.501955	-84.94642	231° SW	314	2

Figure 5. Columbus State College has a big field of trees adjacent to an open space.

Manchester Expressway Park and Ride Bike Park 2-3-17

When:	2/3/2017 16:30-17:18 EDT
Who:	K. Youngquist and Trevor Gundberg
Where:	Manchester Expressway Park and Ride Bike Park, 3690 Manchester Expy, Columbus, GA 31909
What:	The bike park has a dense patch of trees surrounding the parking lot and playground on all sides except the north entrance to parking lot. Test beyond tree line compared to parking lot.
How:	Unit #1 in open and #3 in tree line. Moved two airbeams at similar distances from road, behind trees and the other in parking lot.
Notes:	Broke pencils and pens, cut session short. Only one other car in parking lot due to cold, windy weather.
Hypothesis:	In the winter, the dense tree line will create a fence, reducing particulate matter farther from the road as compared with open parking lot without trees.

Particulate Notes

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
16:00	8.8
17:00	5.5
18:00	6.1

Weather

Weather.com: Cloudy the whole time

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)
16:30	NNW	11	55	68	45	30.21
17:18	NNW	11	55	66	44	30.20

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Direction (°)	Wind Speed (mph)	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
16:35	NNW	337.5	3.1	13.8	66.2	8.2	11	29.8	113
16:40	NNW	337.5	6.4	13.4	69.2	7.9	10.4	29.79	110
16:45	NNW	337.5	7.5	13.5	68.3	7.6	10.2	29.79	106
16:50	NNW	337.5	5.1	13	68.5	7.4	9.9	29.8	105
16:55	NNW	337.5	5.6	13	69.4	7.5	10.1	29.71	105
17:00	NNW	337.5	3.4	13	68.6	7.3	9.8	29.8	101
17:05	NNW	337.5	4.1	13.2	67.4	7.3	10.0	29.8	96
17:10	NNW	337.5	9.8	12.7	69.2	7.3	9.9	29.8	96
17:15	NW	315	7.2	13.1	68.3	7.3	9.9	29.8	93

Airbeam Location:

Time	Lat A1	Long A1	Lat A3	Long A3	Device Facing Direction (°)	Elevation (ft)	Location
16:34-16:46	32.508447°	-84.935431°	32.508608°	-84.934950°	N 338°	340	1
16:49-17:01	32.508347°	-84.935400°	32.508525°	-84.934833°	N 338°	340	2
17:06-17:18	32.508233°	-84.935347°	32.508444°	-84.934811°	N 338°	340	3

Figure 6. The Bike Park has U-shaped tree canopy with an open area in the center adjacent to Manchester Expressway.

All Saints Presbyterian Church 2-9-17

When:	2-9-17 16:30-17:30
Who:	K. Youngquist (Alone)
Where:	All Saints Presbyterian Church, 7170 Beaver Run Rd, Midland, GA 31820
What:	All Saints has a dense patch of trees surrounding the parking lot. Test in trees and beyond tree line compared to parking lot.
How:	Start/end three airbeams at distance from road. Pick two with closest averages and peaks. Leave third at start location. Move two comparable airbeams at similar distances from road, one in trees and the other in parking lot.
Hypothesis:	In the winter, trees will create a fence, reducing particulate matter farther from the road in trees as compared with open parking lot without trees.

Particulate Notes

Time	Notes
16:39	Truck idling and all airbeams particulate count increased.

Car Data:

Time	Cars	Minutes	Cars/Min
16:36	45	2	22.5
16:53	66	2	33
17:10	91	2	45.5

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
15:00	0.4
16:00	2.1
17:00	2.9
18:00	1.1

Weather

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)
16:34	NNW	14	55	32	26	30.24

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Direction (°)	Wind Speed (mph)	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
16:24	N	360	16	12.2	35.3	-2.7	5.7	29.72	173
16:35	N	360	8.2	12.6	38.5	-1.2	6.3	29.73	178
16:40	NNW	337.5	5.6	12.9	37.5	-1.0	6.5	29.72	178
16:45	NNW	337.5	7.2	12.1	38.8	-1.2	6.2	29.74	157
16:50	NNW	337.5	6.4	12.6	39.3	-0.8	6.5	29.73	165
16:55	N	360	13.4	12.1	38.3	-1.6	6	29.73	165
17:05	N	360	2.9	12.6	36.1	-2.0	6.1	29.77	136
17:10	N	360	11	11.9	37.3	-1.9	5.9	29.75	148
17:18	N	360	14.6	11.5	37.7	-2.5	5.4	29.76	140
17:24	N	360	8.9	11.9	37.7	-2.5	5.5	29.75	153

Airbeam Location Data:

Time	Lat A1	Long A1	Lat A2	Long A2	Lat A3	Long A3	Device Facing Direction (°)	Elevation (ft)	Location	Notes
16:31-16:46	32.537679°	-84.867638°	32.537679°	-84.867639°	32.537679°	-84.867637°	360° N	410	Start	In front of cross at entrance
16:49-16:59	32.537368°	-84.867639°	32.537679°	-84.867639°	32.537362°	-84.867162°	360° N	410	1	
17:04-17:13	32.537183°	-84.867636°	32.537679°	-84.867639°	32.537126°	-84.867166°	360° N	410	2	
17:17-17:20	32.537368°	-84.867639°	32.537679°	-84.867639°	32.537362°	-84.867162°	360° N	410	1	#1 fell at 5:20 due to wind
17:23-17:25	32.537679°	-84.867638°	32.537679°	-84.867639°	32.537679°	-84.867637°	360° N	410	End	#3 fell at 5:25 due to wind

Figure 7. All Saints Presbyterian Church location represents a U-shaped tree arrangement with an open field in the center adjacent to highway 80.

Cascade Hills Church 2-10-17

When:	2/10/2017 16:20-17:00 EDT
Who:	K. Youngquist and Trevor Gundberg
Where:	Cascade Hills Church, 54th Street, Columbus, GA 31904
What:	Cascade has a thin line of trees east of the church building. Test beyond thin tree line compared to parking lot.
How:	Start/end three airbeams at fence boarder facing highway. Pick two with closest averages and peaks. Leave third at start location. Move two comparable airbeams at same distances from road, behind trees and the other in parking lot.
Notes:	Started second location, but church event caused early end. End equivalency test not performed due to manager informing us it was time to leave.
Hypothesis:	In the winter, trees will create a fence, reducing particulate matter farther from the road as compared with open parking lot without trees.

Particulate Notes

Car Data:

Time	Cars (Trevor Count)	Cars (Kristin Count)	Minutes	Cars/Min
16:27	179	183	2	91
16:41	219	212	2	108

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
16:00	0.7
17:00	1.1
18:00	3.3

Weather

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)
16:14	SSE	8	67	20	23	30.30
16:59	S	10	67	20	24	30.30

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Direction (°)	Wind Speed (mph)	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
16:24	SSW	202.5	1.4	21.5	19.1	-3.5	9.4	29.83	166
16:31	SSW	202.5	1.8	21.1	19.7	-3.3	9.4	29.74	158
16:39	SSW	202.5	3.2	19.7	19.8	-3.4	9.6	29.75	140

Airbeam Location Data (My iphone):

Time	Lat A1	Long A1	Lat A2	Long A2	Lat A3	Long A3	Device Facing Direction (°)	Elevation (ft)	Location
16:21-16:31	32.523491°	-84.982631°	32.523491°	-84.982631°	32.523491°	-84.982631°	338 NW	420	Start
16:35-16:40	32.523335°	-84.982998°	32.523491°	-84.982631°	32.523673°	-84.982118°	338 NW	420	1
16:43-16:44	32.523103°	-84.983225°	32.523491°	-84.982631°	32.523611°	-84.981942°	338 NW	420	2

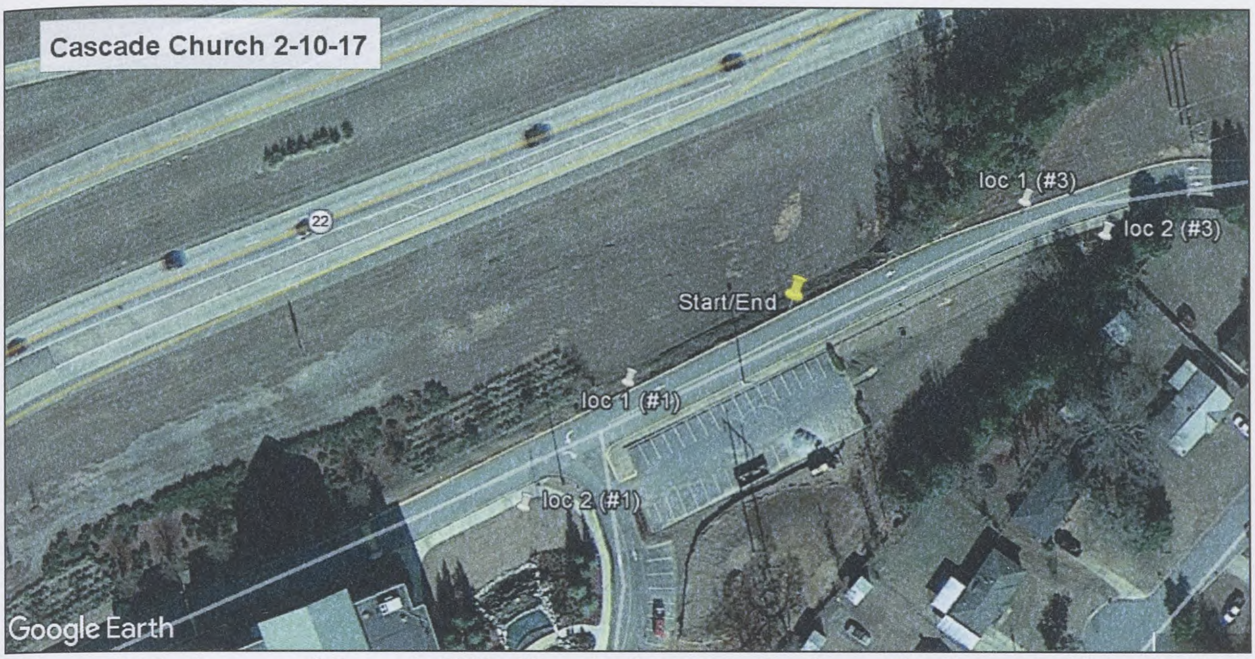

Figure 8. To the east of Cascade Hills Church, the tree buffer is small adjacent to highway 80.

Manchester Expressway Park and Ride Bike Park 2-13-17

When:	2/13/2017 17:00-18:00 ET
Who:	K. Youngquist and Trevor Gundberg
Where:	Manchester Expressway Park and Ride Bike Park, 3690 Manchester Expy, Columbus, GA 31909
What:	The bike park has a dense patch of trees surrounding the parking lot and playground on all sides except the north entrance to parking lot. Test beyond tree line compared to parking lot.
How:	Start/end three airbeams at distance 70 ft from road in grass north of parking lot. Pick two with closest averages and peaks. Leave third at start location. Move two comparable airbeams at similar distances from road, behind trees and the other in parking lot.
Notes:	1 and 2 were not set to record until 5:21pm and 5:34pm respectively. Closest airbeams based on averages and peaks during start will be used moving forward (as was done on west side of parking lot) and not previous equivalency tests.
Hypothesis:	In the winter, the dense tree line will create a fence, reducing particulate matter farther from the road along tree line as compared with open parking lot without trees.

Particulate Notes

Car Data:

Time	Cars (Trevor Count)	Cars (Kristin Count)	Minutes	Cars/Min
17:06	129	131	2	65
17:56	122	122	2	61

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
16:00	6.1
17:00	8.5
18:00	23

Weather

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)	Note
17:00	N	6	73	15	25	30.06	Sunny

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Direction (°)	Wind Speed (mph)	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
17:06	N	360	4.8	23.1	20.6	-0.7	11.3	29.62	268
17:16	NNW	337.5	2.6	23.1	20.6	-0.8	11.3	29.63	268
17:26	NNW	337.5	3.7	22.7	19.8	-1.3	11.1	29.64	255
17:36	NNW	337.5	3.8	22.2	21.2	-1.1	10.7	29.63	260
17:46	NNW	337.5	4.5	21.5	21.8	-1.2	10.5	29.64	250
17:55	NNW	337.5	4.7	21.2	22.9	-0.9	10.4	29.65	243

Airbeam Location:

Time	Lat A1	Long A1	Lat A2	Long A2	Lat A3	Long A3	Device Facing Direction (°)	Elevation (ft)	Location
17:21-17:24	32.508447	-84.935431	32.508535	-84.935441	32.508608	-84.934950	NW 338°	340	East 1
17:26-17:32	32.508222	-84.935306	32.508535	-84.935441	32.508425	-84.934786	NW 338°	340	East 2
17:34-17:40	32.508535	-84.935441	32.508535	-84.935441	32.508535	-84.935441	NW 338°	340	East End
17:46-17:48	32.508092	-84.936525	32.508099	-84.936521	32.508092	-84.936522	NW 338°	340	West Start
17:50-17:53	32.508092	-84.936525	32.507795	-84.936710	32.507850	-84.936514	NW 338°	340	West 1
17:56-18:00	32.508092	-84.936525	32.508099	-84.936521	32.508092	-84.936525	NW 338°	340	West End

Figure 9. The Bike Park has U-shape tree canopy with an open area in the center adjacent to Manchester Expressway.

Cascade Hills Church 2-15-17

When: 2/15/2017 5-5:10pm

Who: K. Youngquist and Trevor Gundberg
Where: Cascade Hills Church, 54th Street, Columbus, GA 31904
What: East of the church building, Cascade has a newly cleared openly in tree line.
How: Started three airbeams at fence boarder facing highway. Moved all back same spot.
Notes: Only did equivalency tests as church members started arriving.

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)	
4:51pm	NNW	17.3	61	36	34	29.75	Clear Skies

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Speed (mph)	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
5:03	NE	1.8	20.4	35.1	2.9	10.4	29.24	608
5:09	NE	1.1	20.4	35.1	2.9	10.4	29.24	608

Airbeam Location:

Time	Lat 1	Long 1	Facing	Elevation (ft)	Notes
5:01-5:07pm	32.524167	84.980556	NW 336°	340	All
5:08-5:10pm	32.524064	84.980511	NW 336°	340	All

Figure 10. To the east of Cascade Hills Church, the tree buffer is small adjacent to highway 80.

Cunningham Center 2-15-17

When:	2/15/2017 17:30-18:15 EDT
Who:	K. Youngquist and Trevor Gundberg
Where:	Cunningham Center, CSU, 3100 Gentian Blvd, Columbus, GA 31907
What:	The Cunningham Center has a thin patch of trees lining the street and part of the parking lot. Test tree line compared to parking lot.
How:	Start/end airbeams at distance 30ft from road in grass north of parking lot near Cunningham sign. Pick two with closest averages and peaks. Leave third at start location. Move two comparable airbeams at same distances from road, behind trees and the other in parking lot.
Notes:	3 was not set to record until 5:36pm. 3 fell over at 5:56 while being moved.
Hypothesis:	In the winter, the small tree line will not impact particulate matter as compared with open parking lot without trees.

Particulate Notes:

Car Data:

Time	Cars (Trevor Count)	Cars (Kristin Count)	Minutes	Cars/Min	Note
18:05	62	67	2	32	5 cars in parking lot at 5:55pm

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
16:00	0.8
17:00	1
18:00	-0.1

Weather

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)	Note
17:51	NW	10.4	61	34	32	29.77	Clear

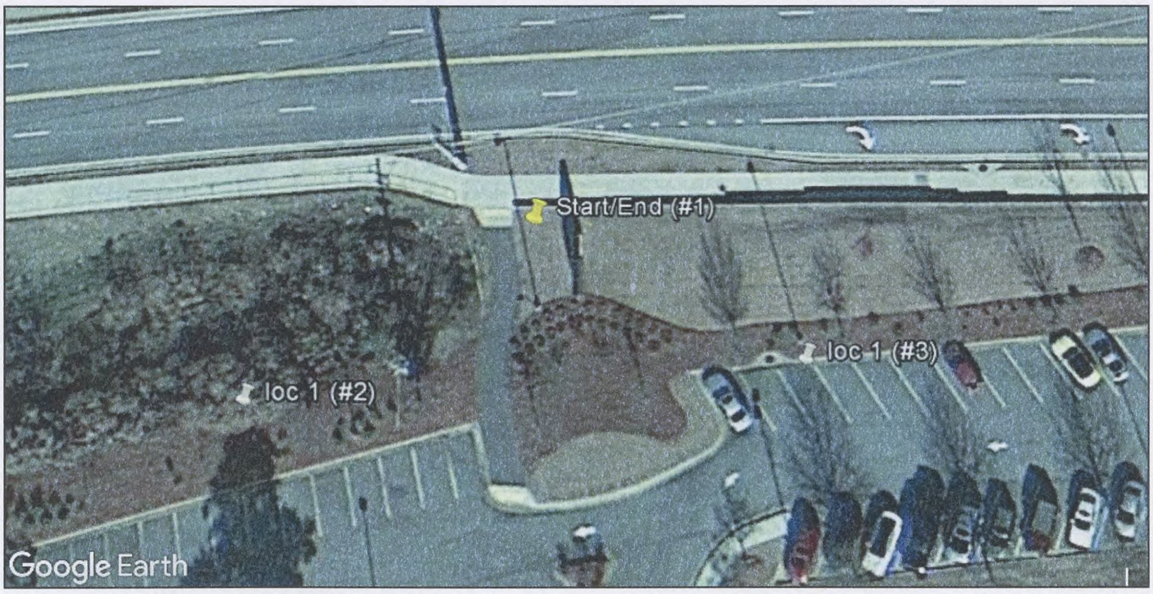

Figure 11. Cunningham Center has thin tree line adjacent to open parking lot.

Manchester Expressway Park and Ride Bike Park 2-17-17

When:	2/17/2017 16:00-18:00 EDT
Who:	K. Youngquist and Care Bacon
Where:	Manchester Expressway Park and Ride Bike Park, 3690 Manchester Expy, Columbus, GA 31909
What:	The bike park has a dense patch of trees surrounding the parking lot and playground on all sides except the north entrance to parking lot. Test beyond tree line compared to parking lot.
How:	Start/end three airbeams close to road in grass at west corner of park. Pick two with closest averages and peaks. Leave third at start location. Move two comparable airbeams at similar distances from road, within trees and along path.
Notes:	Testing started at 4:21pm, but airbeam 3 data (in the tree line) was not saved. So analysis can not be conducted.
Hypothesis:	The trees will create a fence, increasing particulate matter in the tree line as compared to open parking lot.

Particulate Notes

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
15:00	3.2
16:00	3.6
17:00	4.4
18:00	8.5
19:00	7.7

Weather

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)
16:04	WSW	7	69	20	29	30.01

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Direction	Wind Speed (mph)	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
16:28			0	22.0	25.3	0.5	10.9	29.57	318
16:45	WSW	247.5	0.8	21.9	26.5	1.9	11.6	29.57	318
16:54	WSW	247.5	1.1	21.7	30.0	3.6	12.2	29.57	315

Airbeam Location:

Time	Lat 1	Long 1	Lat 2	Long 2	Facing	Elevation (ft)	Location
16:26-16:37	32.5080417°	-84.9366306°	32.5080417°	-84.9366250°	338° NW	330	Start
16:39-16:46	32.5080417°	-84.9366306°	32.5078417°	-84.9367417°	338° NW	330	1

Figure 12. The Bike Park has U-shape tree canopy with an open area in the center adjacent to Manchester Expressway.

Corner of University and Manchester

When:	2/17/2017 17:00-18:00 EDT
Who:	K. Youngquist and Care Bacon
Where:	Fall Line Bike Path - Corner of University and Manchester
What:	The bike path has a tunnel of trees surrounding the path. Test on path and in tree line at distance from street.
How:	Start/end three airbeams 10ft from road in grass at corner. Pick two with closest averages and peaks. Leave third at start location. Move two comparable airbeams at similar distances from road, within trees and along path in open area.
Notes:	Smoke from Burger King across the street started around 17:34 and was picked up by units 2 and 3 farther from sources as compared with unit 1 closest to source at start/end location.
Hypothesis:	The trees will create a fence, reducing particulate matter in the tree line while increasing it within the tunnel created by the trees as move away from the road.

Particulate Notes

Car Data:

Time	Cars (Care Count)	Cars (Kristin Count)	Minutes	Cars/Min
17:15	168	168	2	84

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
15:00	3.2
16:00	3.6
17:00	4.4
18:00	8.5
19:00	7.7

Weather

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)
16:04	WSW	7	69	20	29	30.01

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Direction (°)	Wind Speed (mph)	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
17:04	W	270	1.4	20.8	28.8	1.8	11	29.57	321
17:14	W	270	2.8	21.1	25.1	0.4	10.7	29.57	313
17:25	WSW	247.5	2.6	20.2	27.4	0.8	10.5	29.58	306
17:34	WSW	247.5	5.2	20.2	26.6	0.4	10.3	29.59	301
17:44	W	270	1.6	20.5	26.1	0.3	10.4	29.59	298

Airbeam Location:

Time	Lat A1	Long A1	Lat A2	Long A2	Lat A3	Long A3	Device Facing Direction (°)	Elevation (ft)	Location
17:12-17:20	32.506806°	-84.939878°	32.506806°	-84.939878°	32.506806°	-84.939878°	300° NW	330	Start
17:23-17:28	32.506806°	-84.939878°	32.506806°	-84.939431°	32.506964°	-84.939458°	248° SW	330	1
17:30-17:39	32.506806°	-84.939878°	32.506919°	-84.939111°	32.507031°	-84.939147°	248° SW	330	2
17:40-17:43	32.506806°	-84.939878°	32.506806°	-84.939878°	32.506806°	-84.939878°	270° W	330	End

Figure 13. Trees create U-shape/tunnel arrangement around bike path at corner of University and Manchester.

Colony Bank 2-19-17

When: 2/19/2017 12:30-13:30 EDT

Who: K. Youngquist

Where: Colony Bank, 1581 Bradley Park Dr, Columbus, GA 31904

What: The bank has U- shape arrangement of trees lining street at Bradley Park Drive and at the back of the bank between the parking lot and the highway 80 on ramp. Test at small opening in tree line and in tree line at distance from street.

How: Start/end three airbeams 15ft from road in grass at SE corner of bank lot. Pick two with closest averages and peaks. Leave third at start location. Move two comparable airbeams at similar distances from road, within trees and along opening in tree line.

Notes: Winds from NNW not in right direction for most traffic idling at stoplights, but only had permission for two days. So moved forward.

Hypothesis: Wind direction will have greater impact reducing tree baracade effect. The dense tree line will not reduce particulate matter farther from the road more as compared with open parking due to wind direction.

Particulate Notes

Car Data:

Time	Cars (Kristin	Minutes	Cars/Min
12:42	93	2	46.5
13:16	92	2	46

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
11:00	7.4
12:00	4.5
13:00	3.3
14:00	2.6

Weather

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)
12:24	NNW	7	67	60	53	30.09

Ambient Weather Data (Krestel 4000):

Time	Wind Direction	Wind Direction (°)	Wind Speed (mph)	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
12:40	NNW	337.5	3.2	22.2	49.1	11.6	15.4	29.56	331
12:52	NNW	337.5	4.6	22.2	51.7	11.8	15.9	29.55	331
12:59	NNW	337.5	3.0	22.2	48.6	11.0	15.5	29.55	331
13:09	NNW	337.5	1.3	24.4	48.1	12.7	17	29.54	343
13:13	NNW	337.5	0.9						
13:19	NW	360	1.9	23.2	47.4	12	16.4	29.51	369

Airbeam Locations:

Time	Lat A1	Long A1	Lat A2	Long A2	Lat A3	Long A3	Device Facing Direction (°)	Elevation (ft)	Location
12:39-12:47	32.532353°	-84.970875°	32.532356°	-84.970875°	32.532350°	-84.970875°	96 E	330	Start
12:50-12:54	32.532283°	-84.970914°	32.532356°	-84.970875°	32.532286°	-84.971067°	96 E	330	1
12:57-13:00	32.532228°	-84.971111°	32.532356°	-84.970875°	32.532222°	-84.971175°	133 SE	330	2
13:08-13:10	32.532244°	-84.971111°	32.532356°	-84.970875°	32.532233°	-84.971381°	170 SE	330	3
13:14-13:17	32.532308°	-84.971372°	32.532356°	-84.970875°	32.532319°	-84.971139°	170 SE		4
13:20-13:22	32.532353°	-84.970875°	32.532356°	-84.970875°	32.53235°	-84.970875°	96 E		End

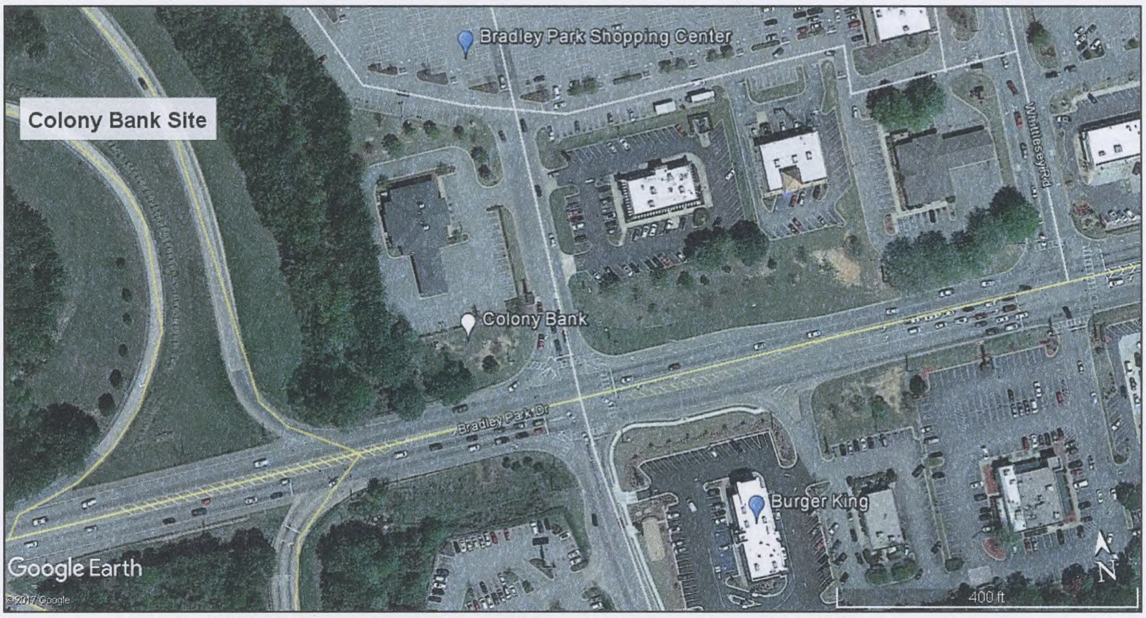

Figure 14. View of Colony Bank and surrounding shopping center area.

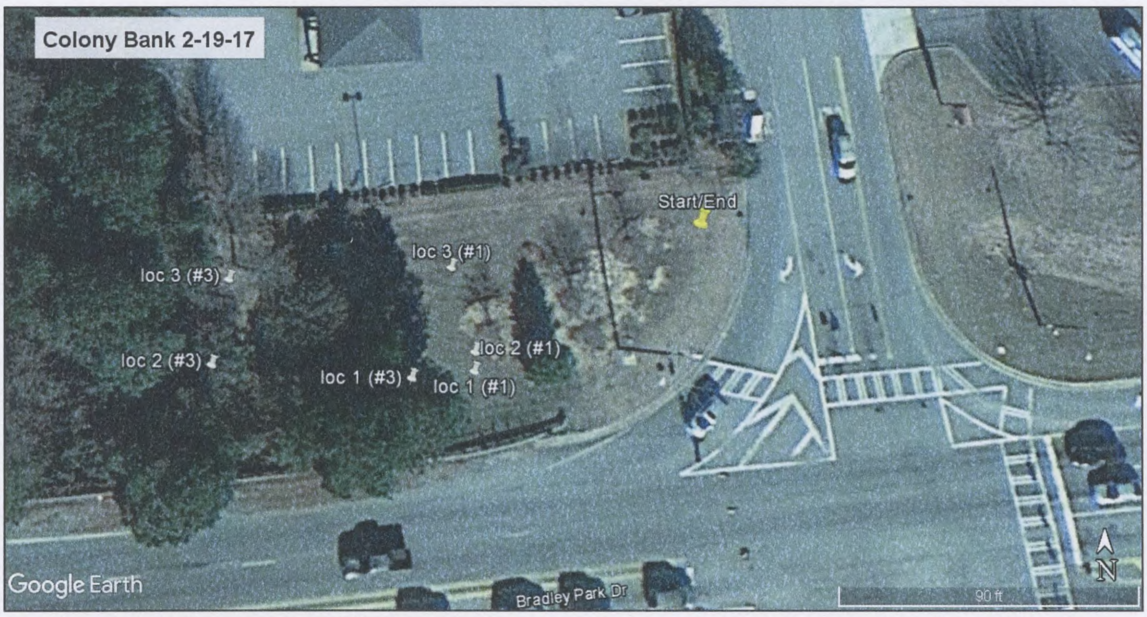

Figure 15. Trees create U-shape tree arrangement around Colony Bank parking lot.

Haverty's and Lazyboy 2-19-17

When:	2/19/2017 14:57-15:55 EDT
Who:	K. Youngquist and Will Kiourtsis
Where:	Havertys and Lazeboy, 5555 Whittlesey Blvd #1000, Columbus, GA 31909
What:	Line of trees at fence separating back of Havertys store from exit/on ramp to highway 80 at Veterans Parkway. Traffic sits at street light waiting to turn onto Veterans. Possible PM build-up at light. Similar situation at street near Lazyboy.
How:	Start/end three airbeams at opening in tree line along fence. Pick two with closest averages and peaks. Leave third at start location. Move two comparable airbeams one in trees and two in openings.
Hypothesis:	The tree dense line will trap particulate matter increasing levels in trees as compared to open areas.

Particulate Notes

Car Data:

Time	Cars (Will Count)	Cars (Kristin	Minutes	Cars/Min
15:04	40	41	1	40.5
15:36	93	93	2	46.5

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
14:00	2.6
15:00	3.8
16:00	3.5
17:00	5.7

Weather

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)
14:57	NW	3	73	43	49	30.04

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Direction (°)	Wind Speed (mph)	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
15:03	WNW	292.5	1.6	24.2	43.9	11.4	16.3	29.44	445
15:14	WNW	292.5	1.6	24.9	44.2	12.7	17.7	29.44	443
15:27	NW	315	3.1	24.7	42.7	11.9	17	29.42	453
15:38	NW	315	1.3	27.2	38.1	11.4	17.5	29.43	448
15:46	WNW	292.5	3.5	26.5	40.3	12.6	17.9	29.43	451
15:53	NW	315	2.5	25.9	39.9	11.2	16.8	29.45	445

Airbeam Location:

Time	Lat A1	Long A1	Lat A2	Long A2	Lat A3	Long A3	Device Facing Direction (°)	Elevation (ft)	Location
15:01-15:08	32.546186°	-84.951300°	32.546189°	-84.951300°	32.546189°	-84.951303°	15 N	470	Start Hav
15:11-15:16	32.546228°	-84.951422°	32.546189°	-84.951300°	32.546178°	-84.951253°	15 N	470	1 Hav
15:18-15:20	32.546186°	-84.951300°	32.546189°	-84.951300°	32.546189°	-84.951303°	15 N	470	End Hav
15:25-15:31	32.545419°	-84.952392°	32.545419°	-84.952394°	32.545422°	-84.952392°	315 NW	485	Start LB
15:33-15:39	32.545419°	-84.952392°	32.545294°	-84.952369°	32.545561°	-84.952222°	315 NW	485	1 LB
15:42-15:48	32.545419°	-84.952392°	32.545292°	-84.952333°	32.545561°	-84.952142°	315 NW	490	2 LB
15:51-15:55	32.545419°	-84.952392°	32.545419°	-84.952394°	32.545422°	-84.952392°	315 NW	490	End LB

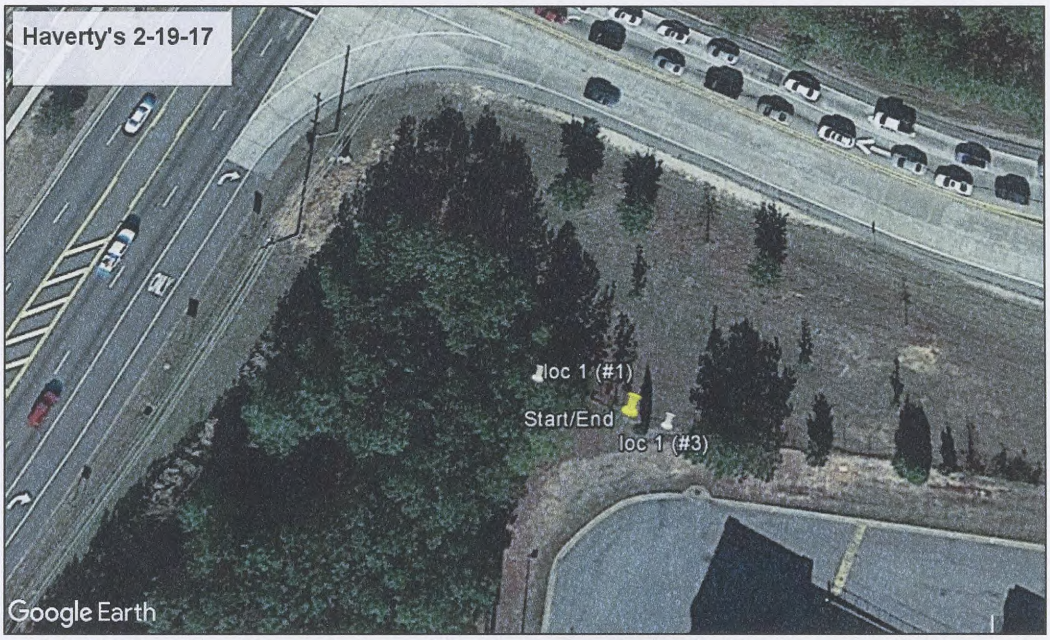

Figure 16. Back side of Haverty's parking lot has a dense field of trees with little opening.

Figure 17. Back side of Lazyboy has a dense field of trees next to grass opening.

Colony Bank 2-20-19

When:	2/20/2017 17:15-18:15 EDT
Who:	K. Youngquist and Trevor Gundberg
Where:	Colony Bank, 1581 Bradley Park Dr, Columbus, GA 31904
What:	The bank has U-shape arrangement of trees lining street at Bradley Park Drive and at the back of the bank between the parking lot and the highway 80 on ramp. Test at small opening in tree line and in tree line at distance from street.
How:	Start/end three airbeams 15ft from road in grass at SE corner of bank lot. Pick two with closest averages and peaks. Leave third at start location. Move two comparable airbeams at similar distances from road, within trees and along opening in tree line.
Notes:	Smoke from Burger King during testing.
Hypothesis:	The dense tree line will create a fence, reducing particulate matter farther from the road more as compared with open parking lot without trees.

Particulate Notes

Car Data:

Time	Cars (Trevor Count)	Cars (Kristin	Minutes	Cars/Min
17:29	74	98	2	43
18:01	74	80	2	38.5

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
16:00	6.4
17:00	7.2
18:00	12.7

Weather

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)
17:20	SSE	6	75	40	49	30.11

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Direction (°)	Wind Speed	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
17:23	SSE	157.5	3.1	24.6	44.9	10.8	16.1	29.58	304
17:33	SSE	157.5	3.3	24.3	42.4	10.7	16	29.58	304
17:40	SSE	157.5	4.0	24.1	43.0	10.7	15.9	29.58	304
17:50	SSE	157.5	4.3	23.9	43.8	10.7	15.9	29.59	296
18:00	SSE	157.5	2.3	23.9	42.9	10.5	15.8	29.59	296

Airbeam Location:

Time	Lat A1	Long A1	Lat A2	Long A2	Lat A3	Long A3	Device Facing Direction (°)	Elevation (ft)	Location
17:19-17:24	32.532281°	-84.970919°	32.532289°	-84.970908°	32.532283°	-84.970914°	135° SE	420	Start
17:27-17:33	32.532206°	-84.971275°	32.532289°	-84.970908°	32.532211°	-84.971100°	158° S	420	1
17:36-17:43	32.532269°	-84.971408°	32.532289°	-84.970908°	32.532297°	-84.971136°	158° S	420	2
17:46-17:53	32.532439°	-84.971469°	32.532289°	-84.970908°	32.532472°	-84.971139°	158° S	420	3
17:56-18:04	32.532281°	-84.970919°	32.532289°	-84.970908°	32.532283°	-84.970914°	135° SE	420	End

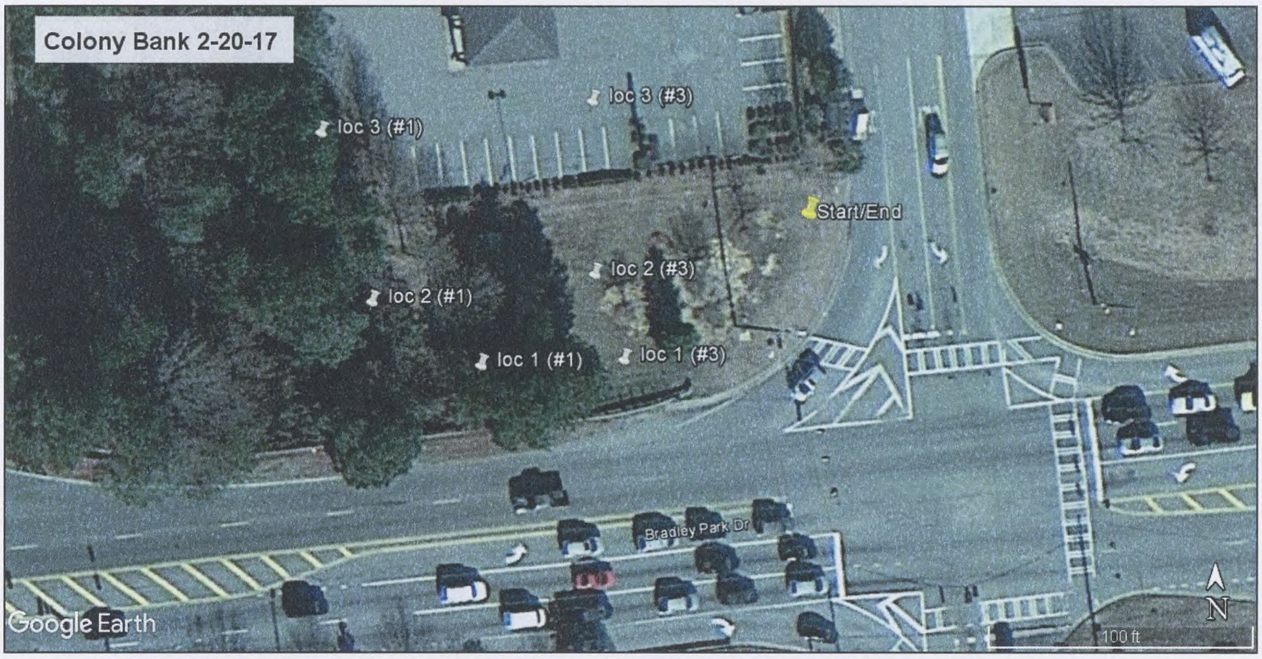

Figure 18. Trees create U-shape tree arrangement around Colony Bank parking lot.

Cascade Hills Church 2-23-17

When: 2/23/2017 7:55-9:05 EDT

Who: K. Youngquist and Dalton Peters

Where: Cascade Hills Church, 54th Street, Columbus, GA 31904

What: Cascade has a line of trees near the entrance to parking lot and a second line of trees past the church building. Test in tree line compared to parking lot.

How: Start/end three airbeams at fence boarder facing highway. Pick two with closest averages and peaks. Leave third at start location. Move two comparable airbeams at similar distances from road, behind trees and the other in parking lot.

Hypothesis: The highway traffic is not close enough to impact PM levels at the church.

Particulate Notes

Car Data:

Time	Cars (Kristin	Cars (Dalton	Minutes	Cars/Min
8:14	190	179	2	92
8:53	148	148	2	74

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
7:00	3.9
8:00	4.2
9:00	3.5
10:00	4.8

Weather

Weather.com:

Time	Wind Direction	Wind Speed	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)
7:57	ENE	5	61	90	58	29.86

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Direction (°)	Wind Speed	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
8:01	ENE	67.5	2.3	16.9	87	14.8	15.6	29.36	510
8:11	ENE	67.5	2.5	17.3	85.9	15.0	15.8	29.37	506
8:21	ENE	67.5	4.9	17.4	85.6	15.0	15.9	29.35	505
8:32	ENE	67.5	7.0	17.2	86.6	15.0	15.8	29.37	501
8:41	ENE	67.5	3.9	17.3	86.7	15.2	16.1	29.38	496
8:51	ESE	112.5	6.1	17.5	87.1	15.4	16.3	29.37	498
9:01	ESE	112.5	4.1	17.3	85.5	15.1	16.0	29.37	501

Airbeam Location:

Time	Lat A1	Long A1	Lat A2	Long A2	Lat A3	Long A3	Device Facing Direction (°)	Elevation (ft)	Location
7:56-8:04	32.522364°	-84.985139°	32.522364°	-84.985144°	32.522361°	-84.985142°	2 N	430	Start W
8:08-8:16	32.522083°	-84.985014°	32.522003°	-84.985547°	32.522361°	-84.985142°	2 N	430	1 W
8:28-8:33	32.522006°	-84.984989°	32.521889°	-84.985639°	32.522361°	-84.985142°	2 N	430	2 W
8:35	32.522364°	-84.985139°	32.522364°	-84.985144°	32.522361°	-84.985142°	2 N	430	End W
8:40-8:46	32.523489°	-84.982633°	32.523492°	-84.982631°	32.523486°	-84.982631°	338 NW	420	Start E
8:48-8:57	32.523672°	-84.982117°	32.523333°	-84.982994°	32.523486°	-84.982631°	338 NW	420	1 E
8:58-9:04	32.523489°	-84.982633°	32.523492°	-84.982631°	32.523486°	-84.982631°	338 NW	420	End E

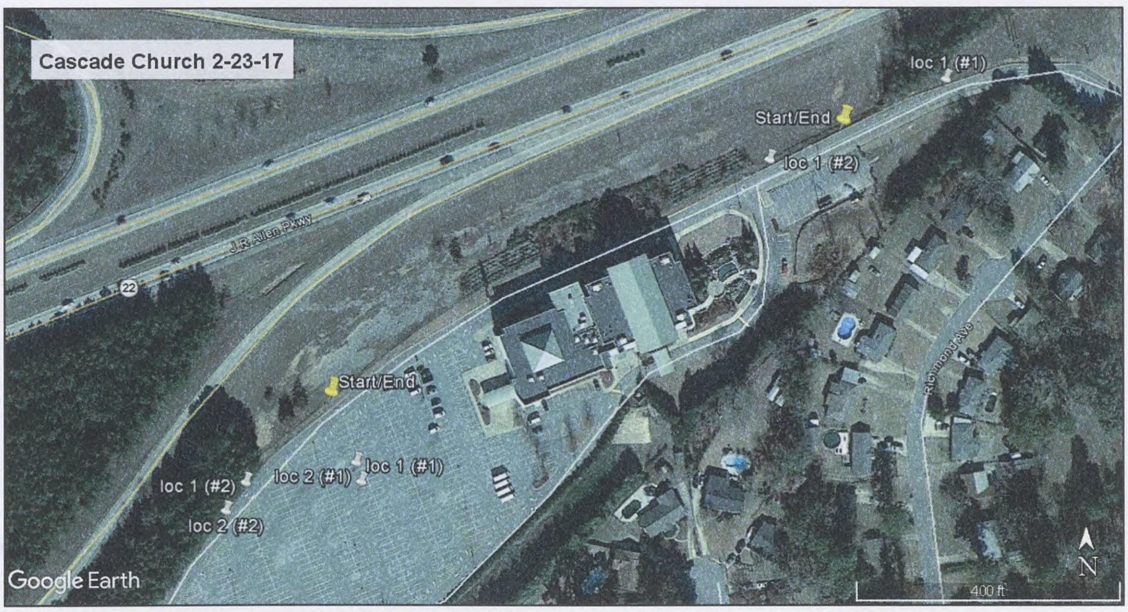

Figure 19. Cascade Hills Church the tree buffer runs parallel to highway 80.

Columbus State University Softball Field 2-23-17

When:	2/23/2017 16:11-17:15 EDT
Who:	K. Youngquist and Kiara Mills
Where:	North of CSU Softball Field, 3100 Gentian Blvd, Columbus, GA 31907
What:	To the north of the CSU softball field, pine trees line the street. Test within tree line compared to open field.
How:	Start/end three airbeams in grass north of parking lot near end of north Cunningham building. Pick two with closest averages and peaks. Leave third at start location. Move two comparable airbeams at similar distances from road within trees and the other in parking lot.
Notes:	Airbeam 2 had trouble connecting. So used 1 and 3 for test. Ended longer to record Airbeam 2 at higher PM levels.
Hypothesis:	The tree tops are not full enough due to pruning to reduce particulate matter more as compared with open area without trees.

Particulate Notes

Car Data:

Time	Cars (Kristin Count)	Cars (Kiara Counted only one side)	Minutes	Cars/Min
16:51	58	38	2	24
17:11	73	52	3	21

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
15:00	0.4
16:00	1.8
17:00	3.1
18:00	3.8

Weather

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)
16:14	E	9	76	45	54	29.80

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Direction (°)	Wind Speed (mph)	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
16:39	E	90	3.3	25.3	47	13.1	17.5	29.36	513
16:49	E	90	2.9	24.8	49	13.4	17.6	29.36	510
17:02	E	90	1	24.7	50.4	13.7	17.6	29.36	510
17:09	E	90	2.1	24.6	50	13.4	17.5	29.36	510

Airbeam Location:

Time	Lat A1	Long A1	Lat A2	Long A2	Lat A3	Long A3	Device Facing Direction (°)	Elevation (ft)	Location
16:31-16:43	32.505614°	-84.941900°	32.505611°	-84.941897°	32.505608°	-84.941894°	75 E	330	Start
16:46-16:55	32.505472°	-84.941839°	32.505611°	-84.941897°	32.505558°	-84.942050°	75 E	330	1
16:58-17:01	32.505333°	-84.941942°	32.505611°	-84.941897°	32.505481°	-84.942197°	85 E	330	2
17:08-17:21	32.505614°	-84.941900°	32.505611°	-84.941897°	32.505608°	-84.941894°	85 E	340	End

Figure 20. North of CSU softball field is a small patch of trees.

St. Mary's United Methodist Church 2-24-17

When: 2/24/2017 15:52-17:06 EDT

Who: K. Youngquist and Kiara Mills

Where: St. Mary's Road UMC, 3993 St Marys Rd, Columbus, GA 31907

What: To the west of St. Mary's Church a thin tree line exists between the church and the highway. Test within tree line compared to open.

How: Start/end three airbeams in open grass on west side of church. Pick two with closest averages and peaks. Leave third at start location. Move two comparable airbeams at similar distances from road within trees and the other in open lawn.

Hypothesis: Thin tree line will not cause difference in particulate levels as compared with open areas.

Particulate Notes

Car Data:

Time	Cars (Kristin	Cars (Kiara Count)	Minutes	Cars/Min
15:59	119	120	2	60
16:38	118	116	2	59

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
15:00	1.6
16:00	4.1
17:00	11.1

Weather

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)
15:52	SSW	6	81	39	54	29.81

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Direction (°)	Wind Speed	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
15:54	SSW	202.5	1.8	27.9	39.7	12.9	18.0	29.36	514
16:04	SW	225	5.4	28.2	43.1	14.4	19.2	29.35	523
16:17	SW	225	3.1	29.1	39.2	14.0	19.3	29.35	514
16:23	SW	225	3.9	28.0	40.6	13.5	18.6	29.35	518
16:34	SW	225	7.6	27.7	42.1	13.7	18.7	29.35	526
16:44	SSW	202.5	5.8	27.4	41.1	13.1	18.2	29.35	523
16:54	SW	225	4.5	27.3	41.8	13.3	18.3	29.34	526
17:04	SW	225	3.8	27.1	40.2	12.4	17.7	29.35	523
17:14	SW	225	5.9	27.0	41.4	12.8	17.9	29.35	526

Airbeam Location:

Time	Lat A1	Long A1	Lat A2	Long A2	Lat A3	Long A3	Device Facing Direction (°)	Elevation (ft)	Location
15:54-16:02	32.446883°	-84.927222°	32.446878°	-84.927222°	32.446881°	-84.927222°	258	340	Start
16:04-16:13	32.446883°	-84.927222°	32.447069°	-84.927183°	32.446772°	-84.927190°	258	340	1
16:14-16:24	32.446883°	-84.927222°	32.447067°	-84.927139°	32.446744°	-84.927142°	258	340	2
16:26-16:36	32.446883°	-84.927222°	32.446878°	-84.927222°	32.446881°	-84.927222°	258	340	End

Figure 21. St. Mary's UMC Church has tree buffer along I-185 with open grass area.

Williams Road 2-28-17

When:	2/28/2017 15:47-17:00 EDT
Who:	K. Youngquist and Dalton Peters
Where:	Williams Road Field across from Shell Gas Station
What:	Cleared field sits beside thick field of trees across the street from gas station and off ramp of I-185. Test within tree line compared to open.
How:	Start/end three airbeams in cleared field near road. Pick two with closest averages and peaks. Leave third at start location. Move two comparable airbeams at similar distances from road, within trees and the other in open field.
Notes:	Calm wind might account for highest particulate at control, as it was closest to street and gas station. Yellow jackets interupted 3rd location test, 3 minutes shorter than others.
Hypothesis:	Trees higher particulate matter, trapping gas station and idling car exhaust.

Particulate Notes

Car Data:

Time	Cars (Kristin	Cars (Dalton Count)	Minutes	Cars/Min
16:02	20	20	1	20
16:59	34	35	2	17

Area PM2.5 via GA EPD Air Branch:

Time	PM2.5
15:00	6.7
16:00	9.3
17:00	10.1
18:00	9.2

Weather

Weather.com:

Time	Wind Direction	Wind Speed (mph)	Temp (°F)	% Humidity	Dew Point (°F)	Pressure (in)
15:47	WSW	7	68	79	61	30.18

Ambient Weather Data (Kestrel 4000):

Time	Wind Direction	Wind Direction (°)	Wind Speed (mph)	Temp (°C)	% Humidity	Dew Point (°C)	Wet Bulb (°C)	Pressure (Hg)	at ft
15:57	SW	225	3.2	20.9	78.0	17.2	18.6	29.56	326
16:09	SW	225	3.9	21.3	77.5	17.5	18.9	29.55	331
16:17	SW	225	1.8	22.9	72.2	17.8	19.6	29.55	335
16:27			0.0	24.5	70.7	18.8	20.6	29.54	345
16:37			0.0	25.0	65.5	17.8	20.0	29.54	348
16:47	Cloudy		0.0	24.0	68.3	17.7	19.8	29.53	356
16:51	SW	225	4.1	Wind picked up but went away at 4:52					
16:57	SW	225	1.2	22.4	73.4	16.7	18.3	29.52	356

Airbeam Location:

Time	Lat A1	Long A1	Lat A2	Long A2	Lat A3	Long A3	Device Facing Direction (°)	Elevation (ft)	Location
15:53-16:05	32.569536°	-84.966475°	32.569536°	-84.966475°	32.569536°	-84.966475°	225	520	Start
16:09-16:18	32.569536°	-84.966475°	32.569447°	-84.966069°	32.569683°	-84.966369°	225	520	1
16:20-16:28	32.569536°	-84.966475°	32.569619°	-84.965933°	32.569797°	-84.966236°	225	520	2
16:31-16:40	32.569536°	-84.966475°	32.569611°	-84.966075°	32.569667°	-84.966169°	225	520	3
16:43-16:52	32.569536°	-84.966475°	32.569475°	-84.966192°	32.569544°	-84.966286°	225	520	4
16:54-17:03	32.569536°	-84.966475°	32.569536°	-84.966475°	32.569536°	-84.966475°	225	520	End

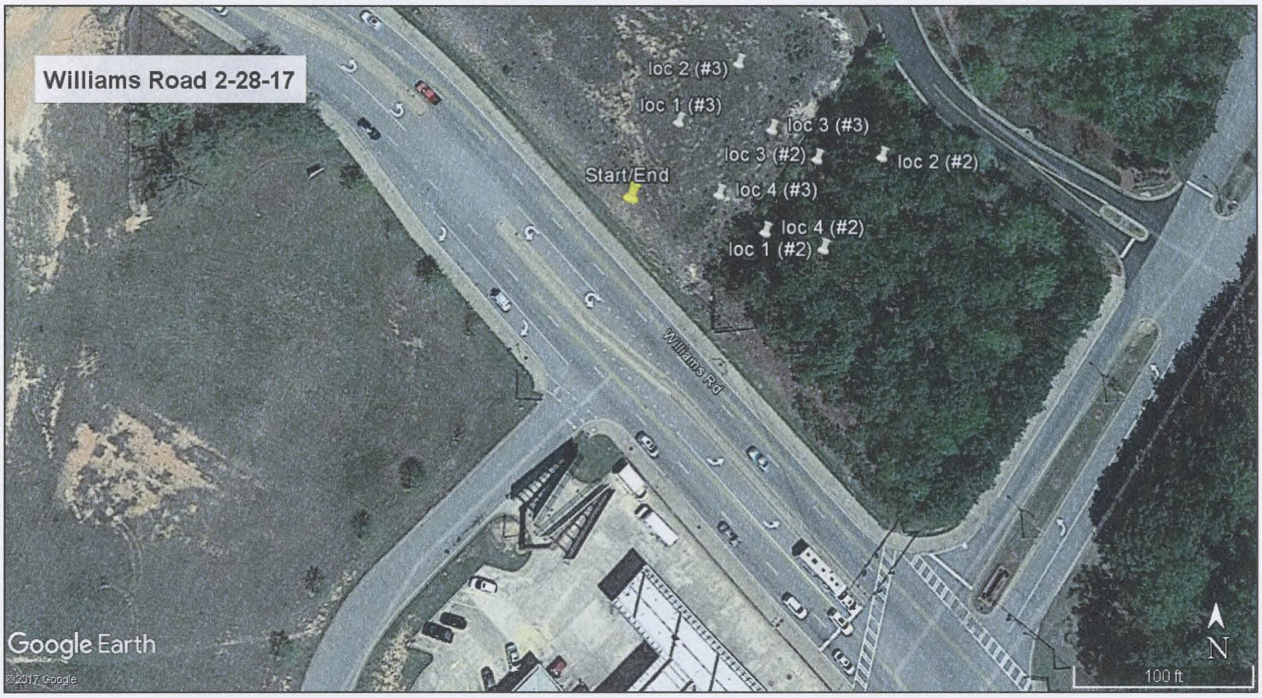

Figure 22. Williams Road has dense tree field next to clear open field.

EVALUATING COLUMBUS, GEORGIA, TREE CANOPY INTERACTIONS WITH AIR POLLUTANTS USING HIGH SPECTRAL IMAGERY AND PORTABLE PM SENSORS

A thesis submitted to the College of Letters and Sciences in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

DEPARTMENT OF EARTH AND SPACE SCIENCES

By

Kristin N. Youngquist

2018

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